Outline #4 Dating Geologic Materials and Landforms

Timescales of climatic variation
-short-term (high frequency) vs long-term (low frequency variation

Dating Glacial Deposits and Landforms
-Relative vs Absolute (Numerical) Dating
-Bracketing Ages (maximum vs minimum ages)

Relative Dating Techniques
-stratigraphic relationships
-landform morphology change
-weathering parameters
-soil chronosequences

Numerical Dating Techniques
-radiocarbon dating
-potassium argon dating
-fission track dating
-uranium-series dating
-thermoluminescence dating
-cosmogenic isotope dating

Age-Equivalent Stratigraphic Markers
-paleomagnetism
-tephrochronology

Incremental Dating Techniques
-dendrochronology
-varve chronology
-lichenometry

Potential Causes of Climate Change versus Time

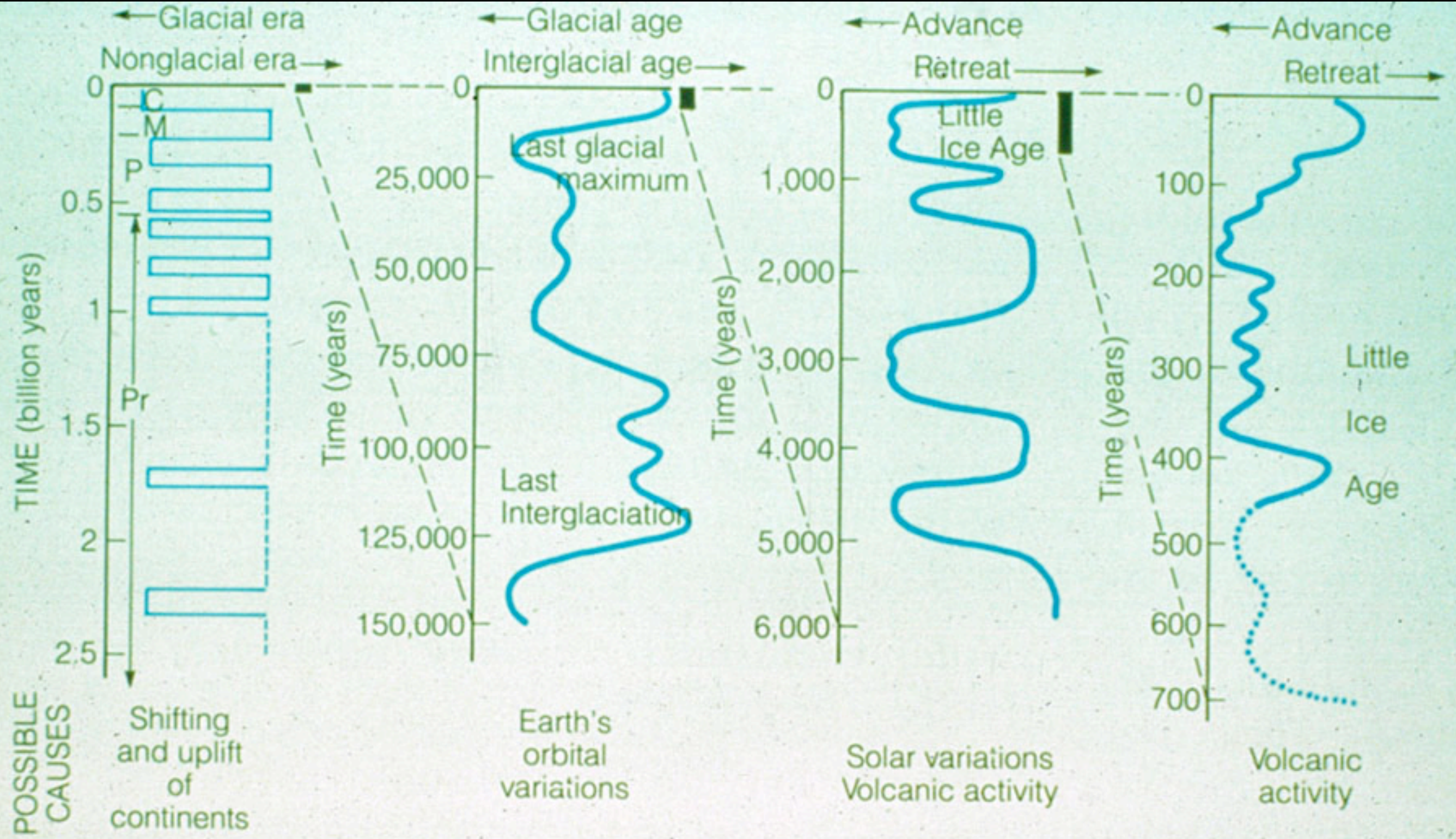


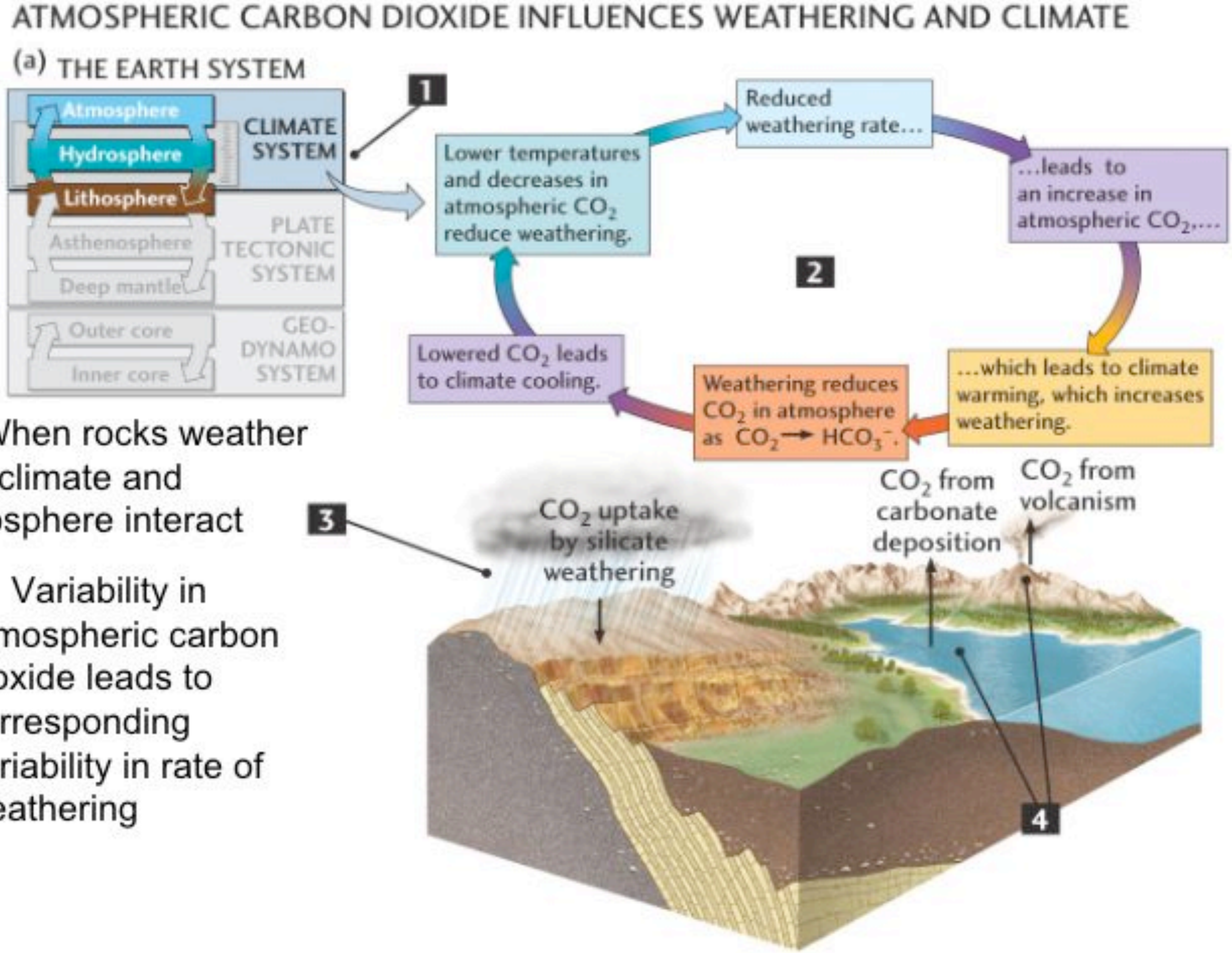
FIGURE 12.23 Time scales of climatic variations and possible causes. In first column: Pr = Proterozoic, P = Paleozoic, M = Mesozoic, and C = Cenozoic.

Relative dating techniques are based on the premise that weathering parameters are time dependent and can be used to differentiate the relative age of surface deposits and landforms, providing all non-temporal factors are held constant. Relative dating techniques by themselves cannot be used to assign independent numerical ages.

Numerical dating allows geologist to assign actual ages to a deposit or landform. Many of the methods are based on the ratio radioactive isotopes and their respective decay products measured in a material to be dated.

In many cases relative dating techniques are used in tandem with numerical dating techniques to constrain the age of a landform or deposit.

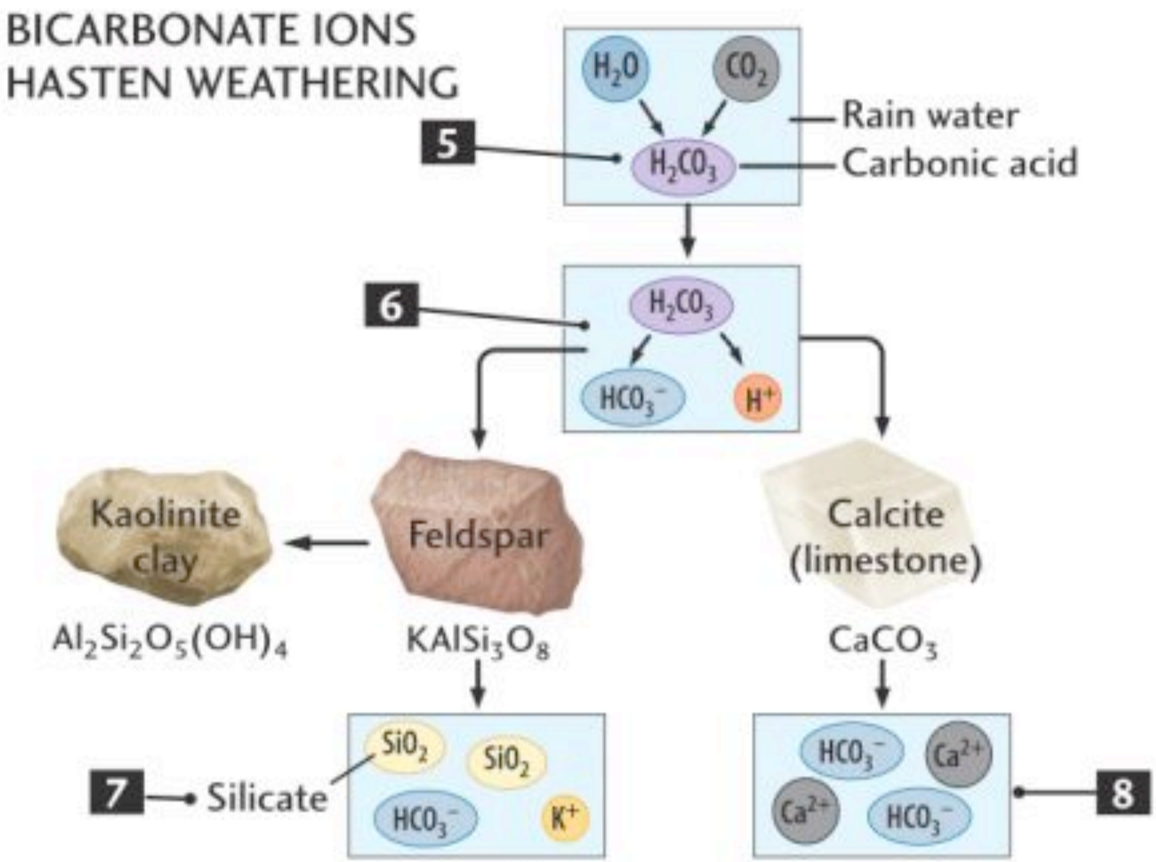
The climate system



1. When rocks weather the climate and lithosphere interact

2. Variability in atmospheric carbon dioxide leads to corresponding variability in rate of weathering

Bicarbonate reactions



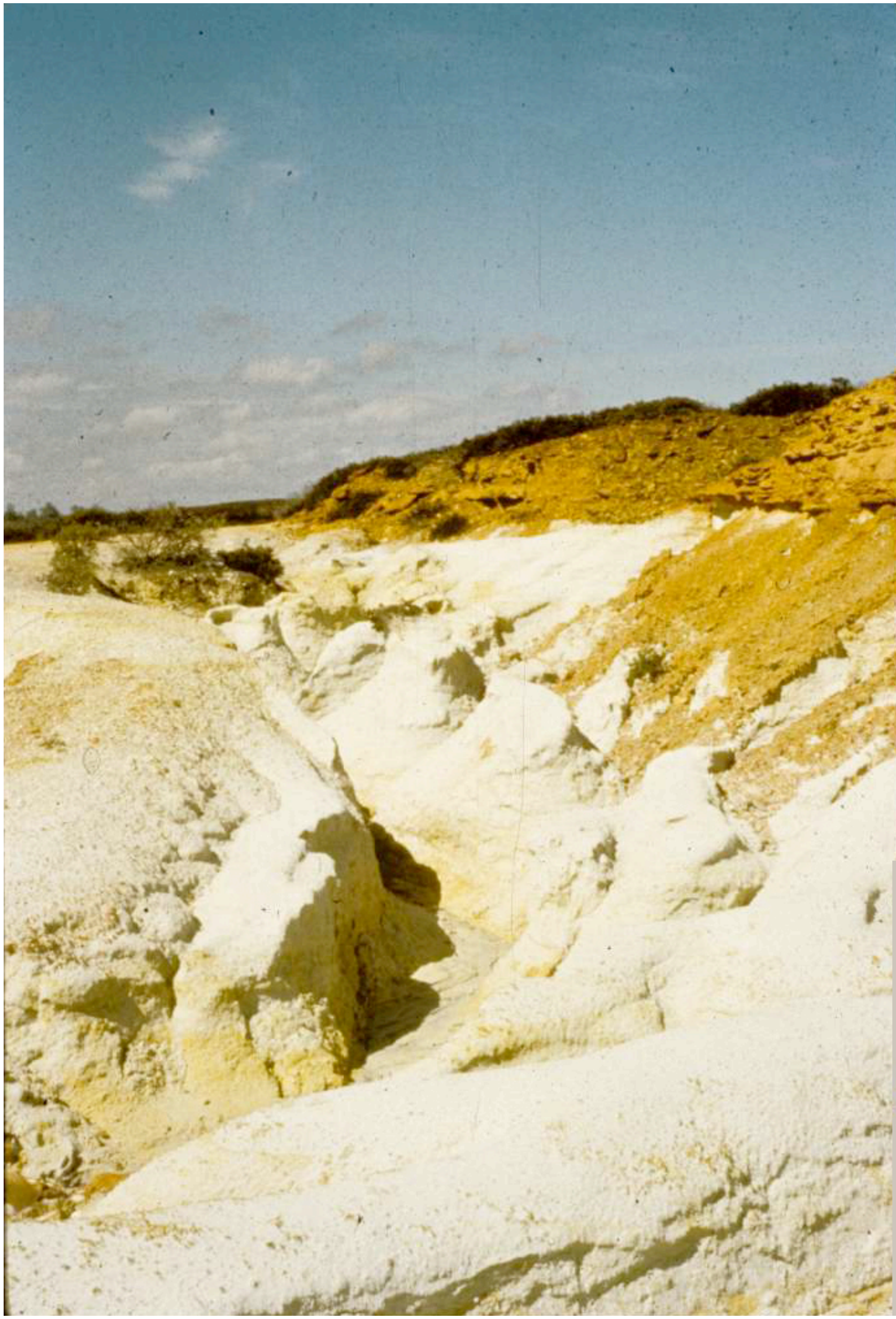
Production of carbonic acid and bicarbonate ions

$$H_2O + CO_2 \longleftrightarrow H_2CO_3 \longleftrightarrow H^{1+} + HCO_3^{1-}$$

Chemical weathering of carbonates

- Easily soluble in water (especially with some acid present)
- Ca and Mg taken into solution

$$CaCO_3 + H_2CO_3 \rightarrow Ca^{2+} + 2HCO_3^-$$



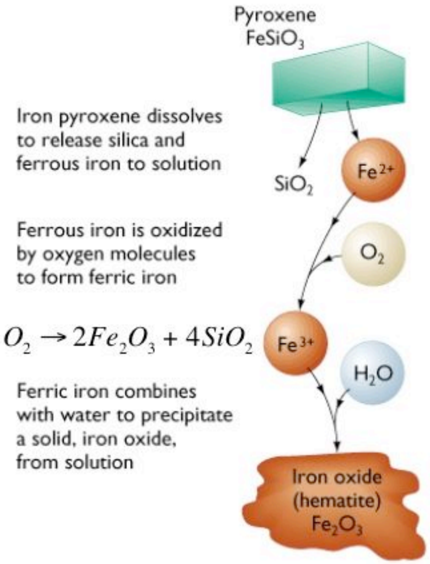
Eocene oxisol, Ione, CA

Iron oxide laterite (red) overlies kaolinite clay (white). Formed on alluvium derived from eroded Sierra Nevada volcanics in a tropical climate 38 m.y. ago.

$$\underbrace{2KAlSi_3O_8}_{\text{potassium feldspar}} + \underbrace{2(H^+ + HCO_3^-)}_{\text{carbonic acid}} + \underbrace{H_2O}_{\text{water}} \longrightarrow$$

$$\underbrace{Al_2Si_2O_5(OH)_4}_{\text{kaolinite (clay)}} + \underbrace{\underbrace{2K^+}_{\text{potassium ion}} + \underbrace{2HCO_3^-}_{\text{bicarbonate ion}} + \underbrace{4SiO_2}_{\text{silica}}}_{\text{in solution}}$$

Oxide formation



$$4FeSiO_3 + O_2 \rightarrow 2Fe_2O_3 + 4SiO_2$$

Ferrous iron (II) soluble

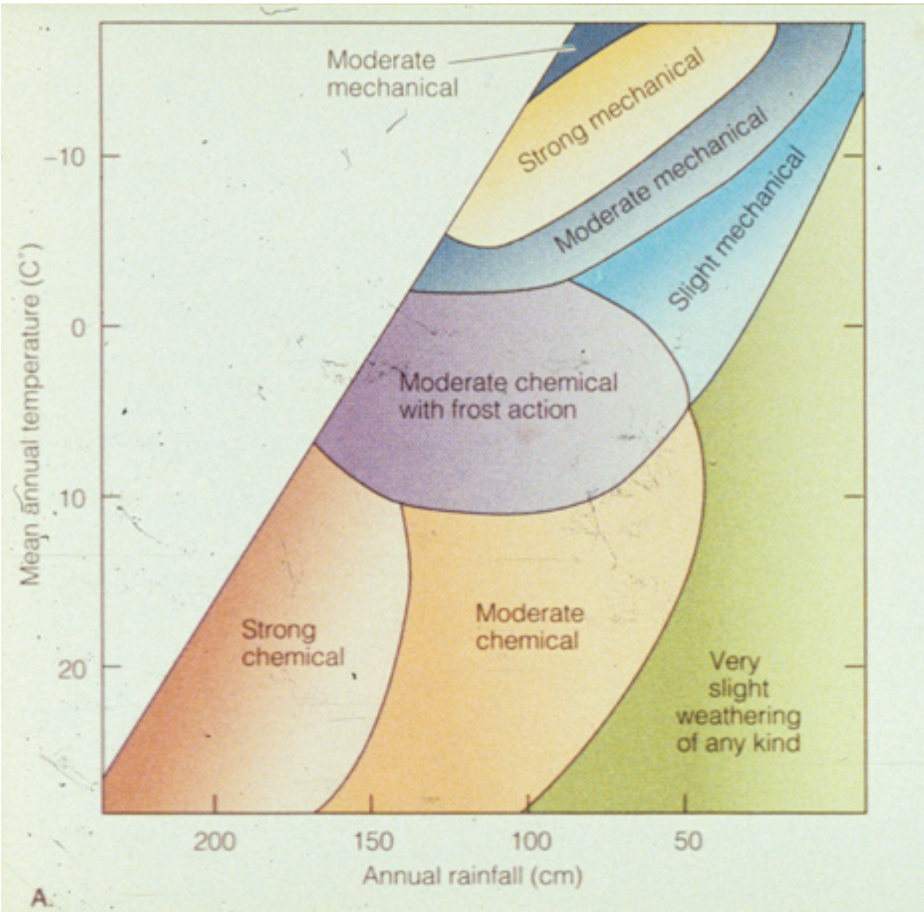
Ferric iron (III) precipitates

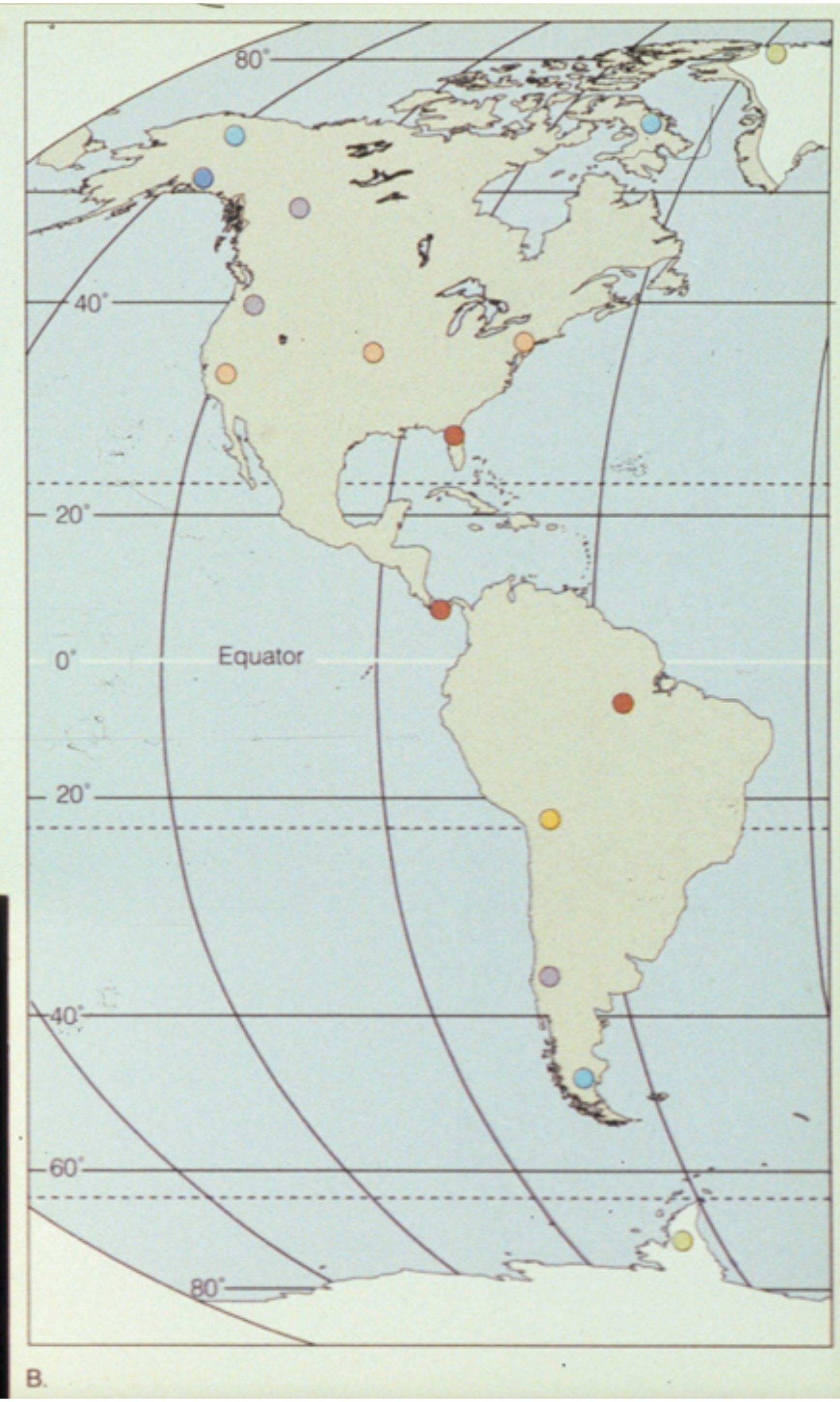
Goethite

$$4FeO + 2H_2O + O_2 \longrightarrow 2FeOOH$$

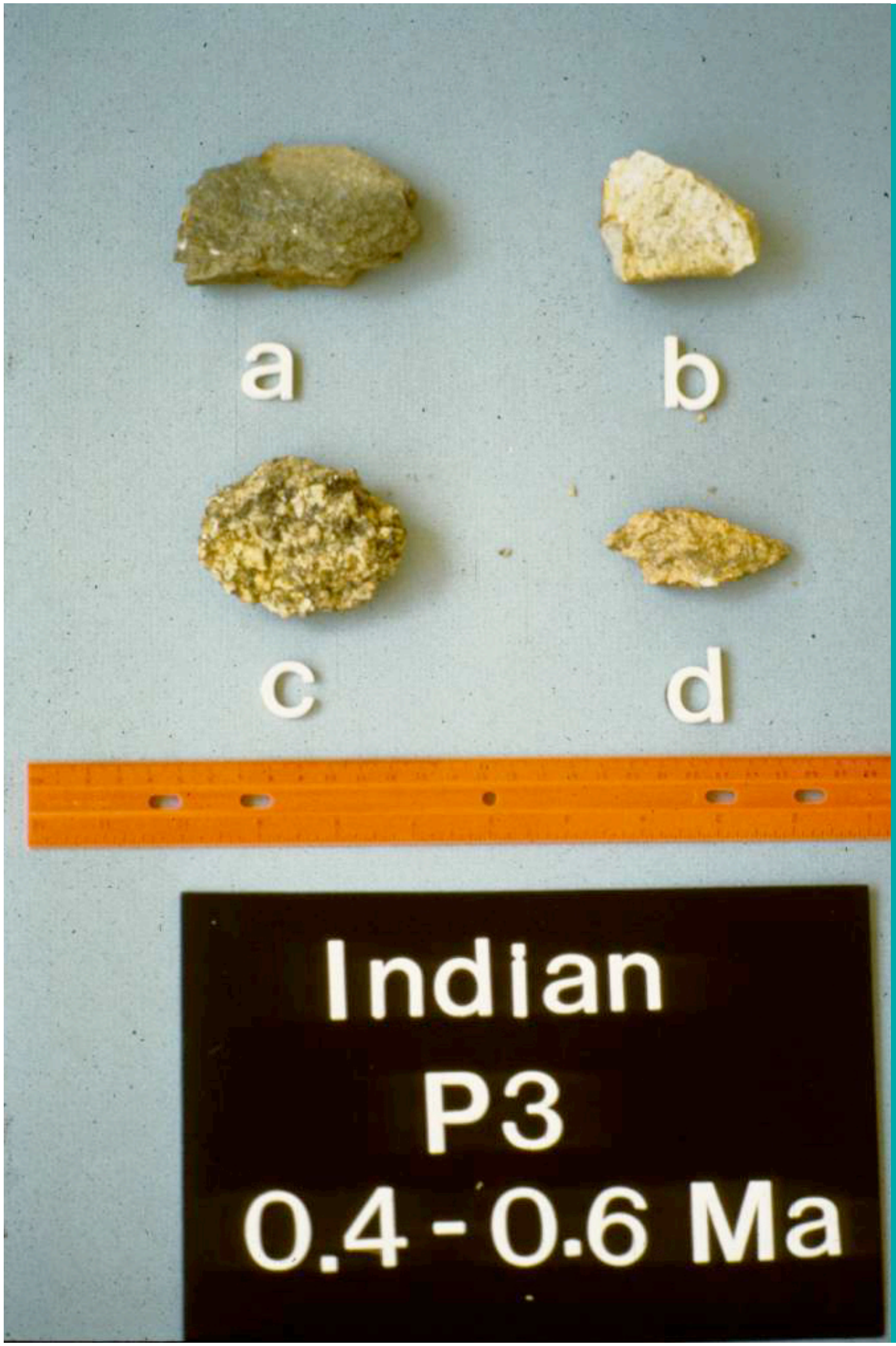
Dehydration to form Hematite

$$2FeOOH \longrightarrow Fe_2O_3 + H_2O$$

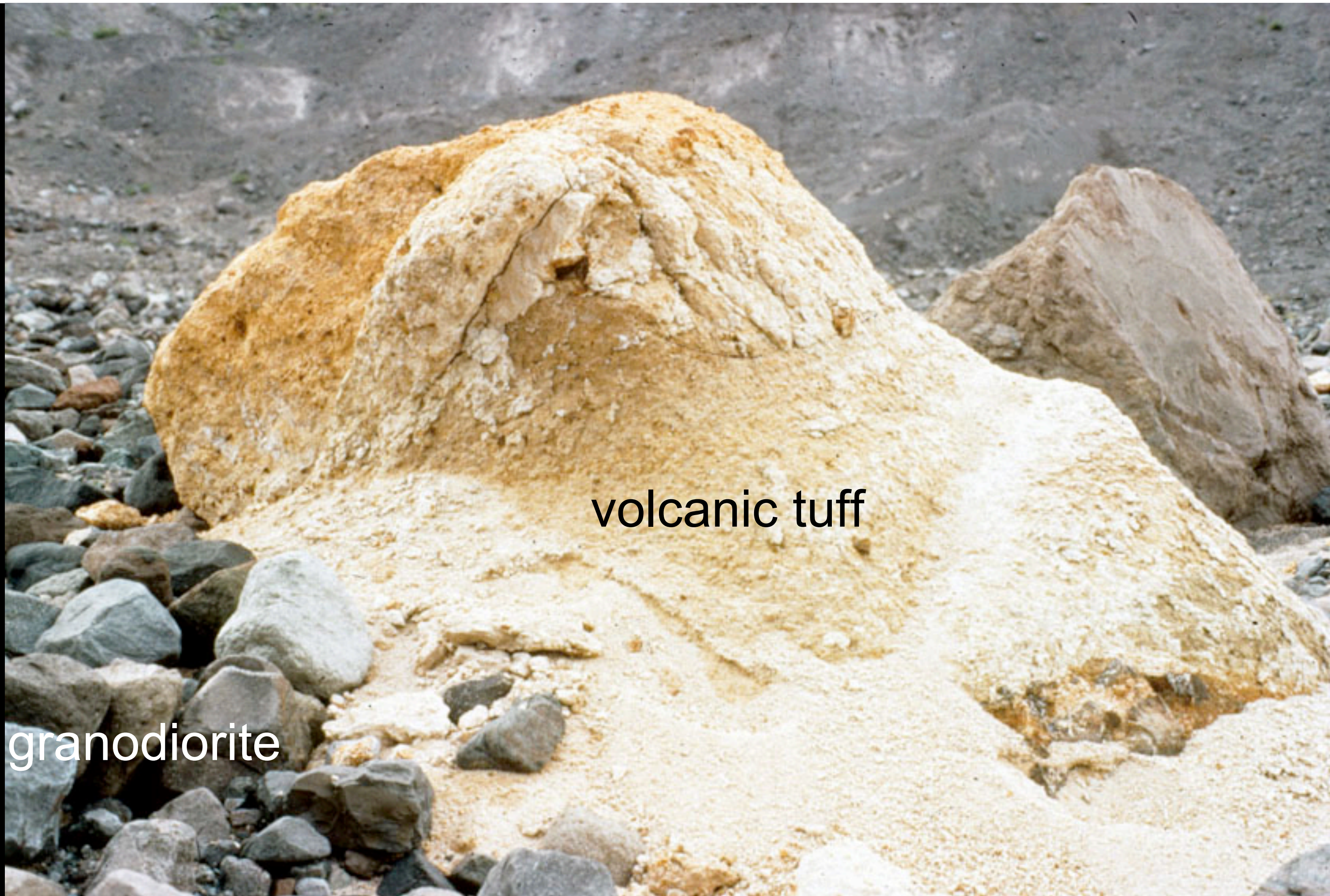




Climatic factors will play a major role in the type of weathering that will occur at a given location.



Lithology plays an important role in weathering rate. Coarse-grained rock containing mafic minerals, such as biotite and amphibole (samples c-diorite and d-volcanic tuff), will weather faster than felsic or fine-grained lithologies (samples a-greenstone and b-aplite). The above rock samples were collected from a soil pit excavated in a glacial moraine in the White Mountains. The moraine is likely younger (0.14-0.18 MA) than that reported on the image.



When using boulder weathering characteristics to compare relative ages of moraines, it important that lithologic composition be held constant, as some lithologies like volcanic tuff weather more rapidly than granitoid lithologies.

Minerals weather at different rates. The sodium-rich plagioclase crystals stand in relief because they are more resistant to chemical weathering processes than the mafic (biotite and amphibole) minerals that are broken down through oxidation reactions Eventually, as the mafic minerals are oxidized and removed from the boulder matrix, the resistant felsic minerals (mainly quartz) will accumulate as unconsolidated grus at the base of the boulder.

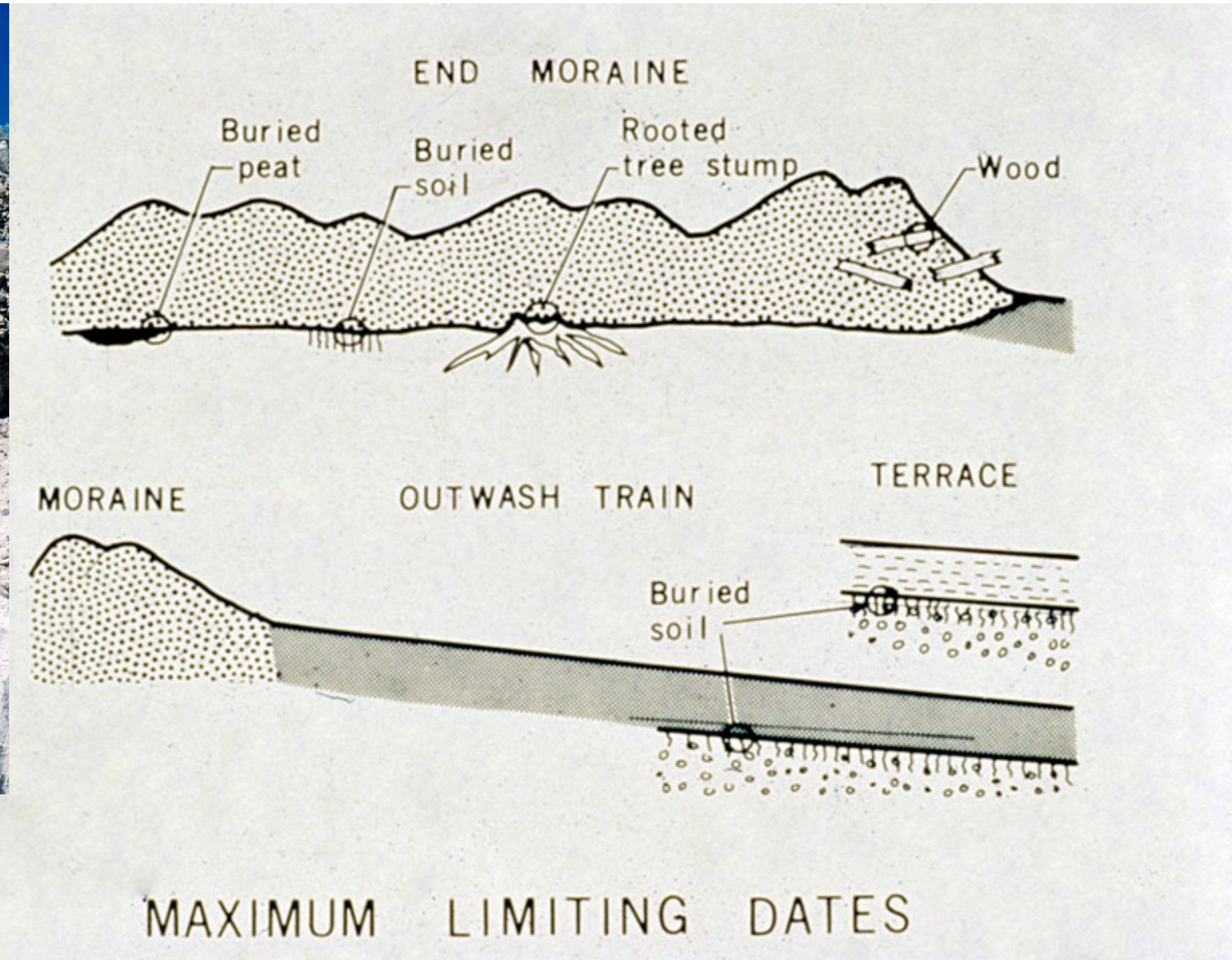
Relative stabilities

Table 7.2 Relative Stabilities of Common Minerals Under Weathering

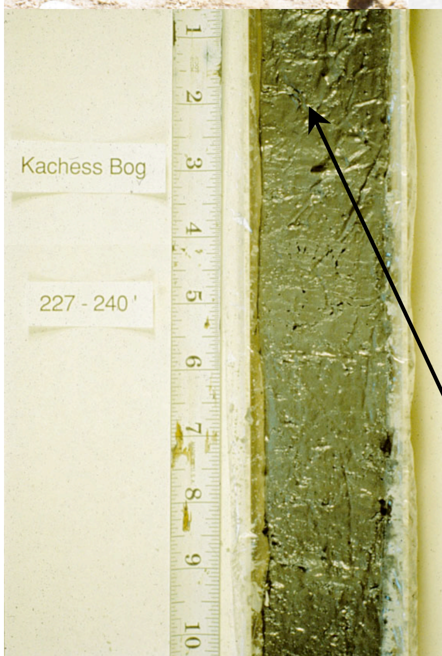
Stability of Minerals	Rate of Weathering
MOST STABLE	Slowest
Iron oxides (hematite)	↓
Aluminum hydroxides (gibbsite)	
Quartz	
Clay minerals	
Muscovite mica	
Potassium feldspar (orthoclase)	
Biotite mica	
Sodium-rich feldspar (albite)	
Amphiboles	
Pyroxene	
Calcium-rich feldspar (anorthite)	
Olivine	
Calcite	
Halite	
LEAST STABLE	Fastest

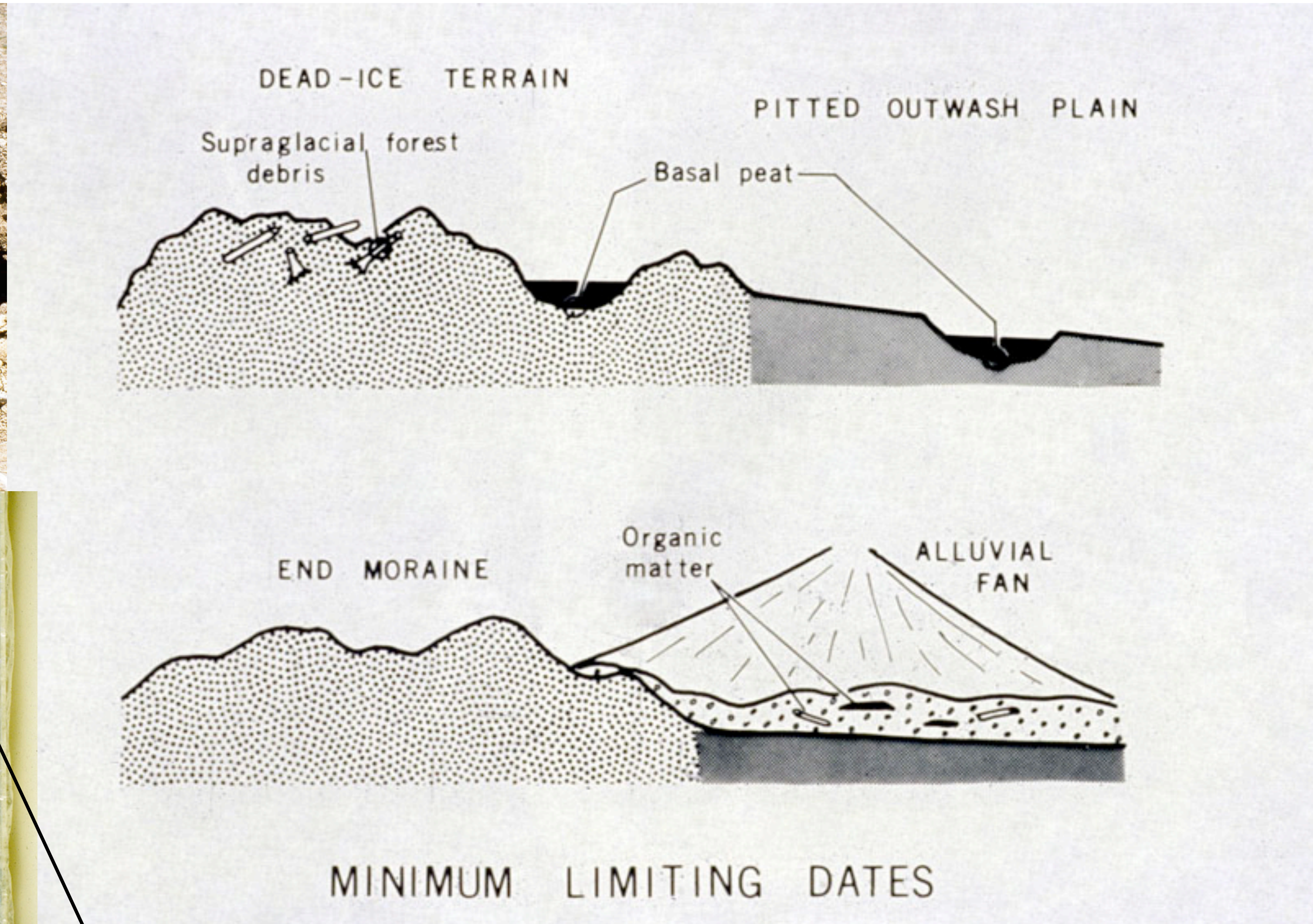
Important factors
-Chemical stability
-Solubility
-Rate of dissolution

Note where common mafic (olivine, Ca-rich plagioclase) pyroxene, amphibole, and biotite) versus felsic (sodium-rich feldspar, potassium feldspar, muscovite mica, quartz) silicate minerals lie on this chart.



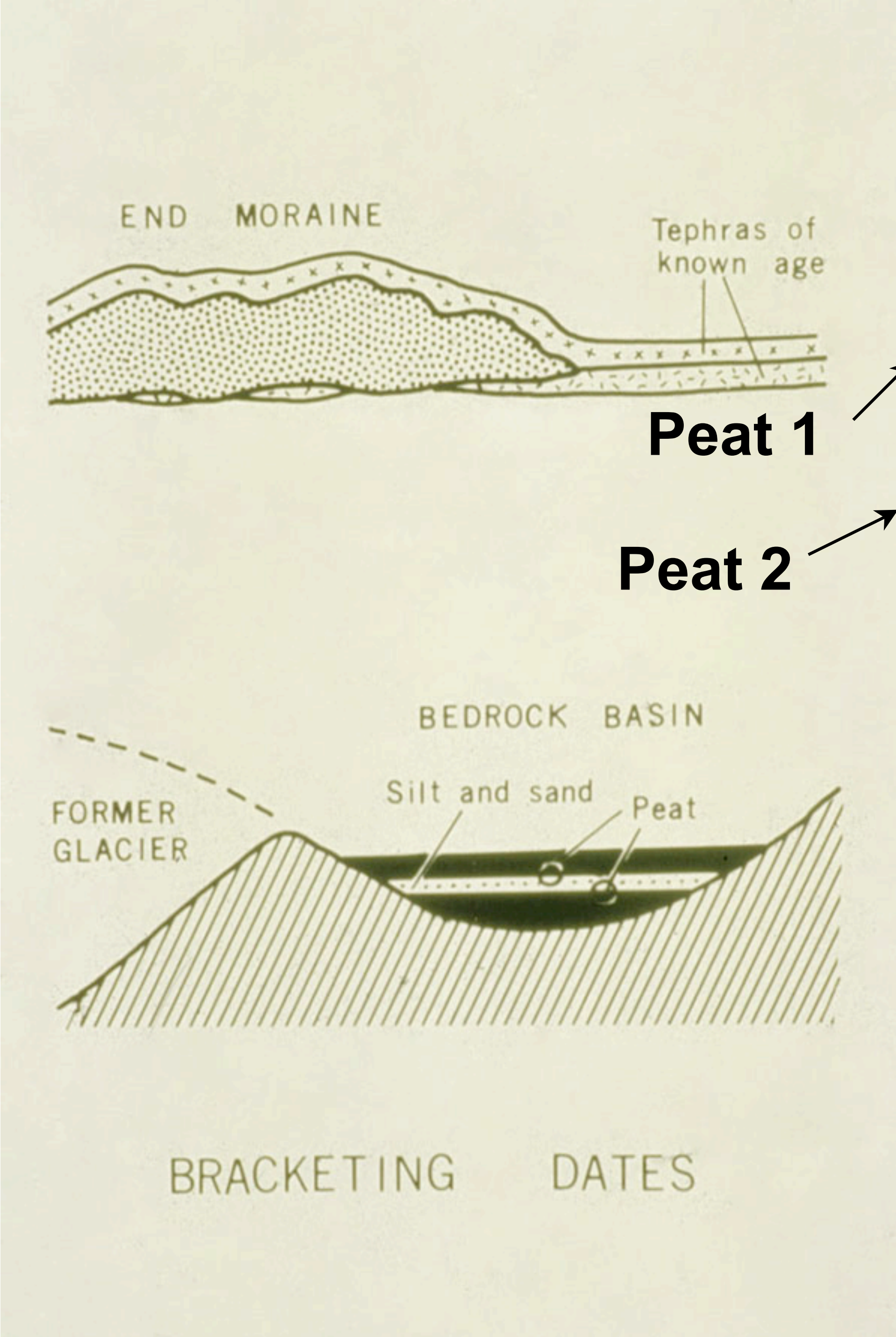
Maximum limiting ages provide constraints on the oldest possible age that a landform or deposit can have. What can you say about the age of the alluvial fan deposit overlying the the Bishop Ash? If you have a group of maximum ages, which age will best constrain the age of the overlying deposit?

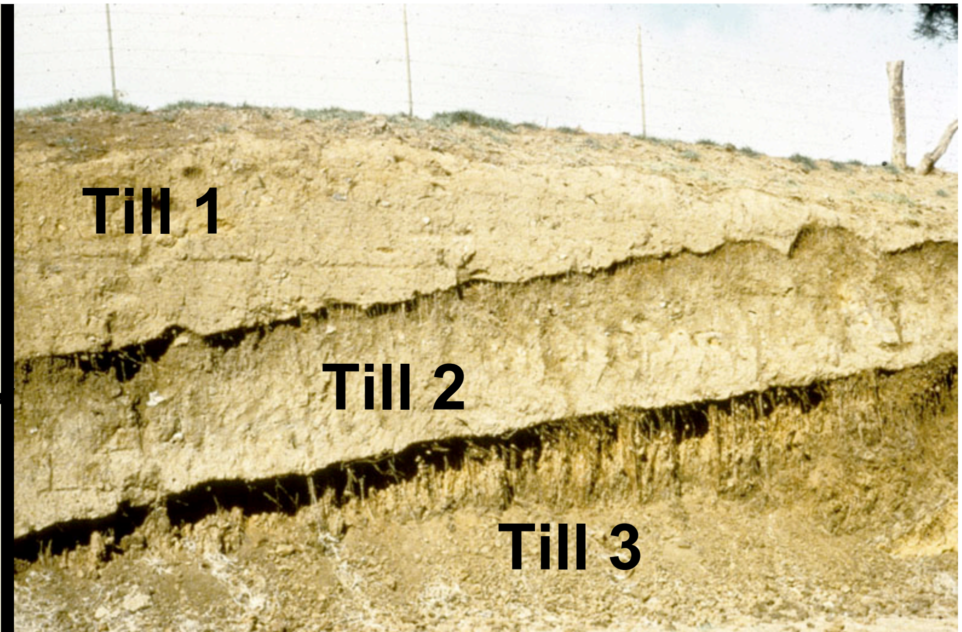




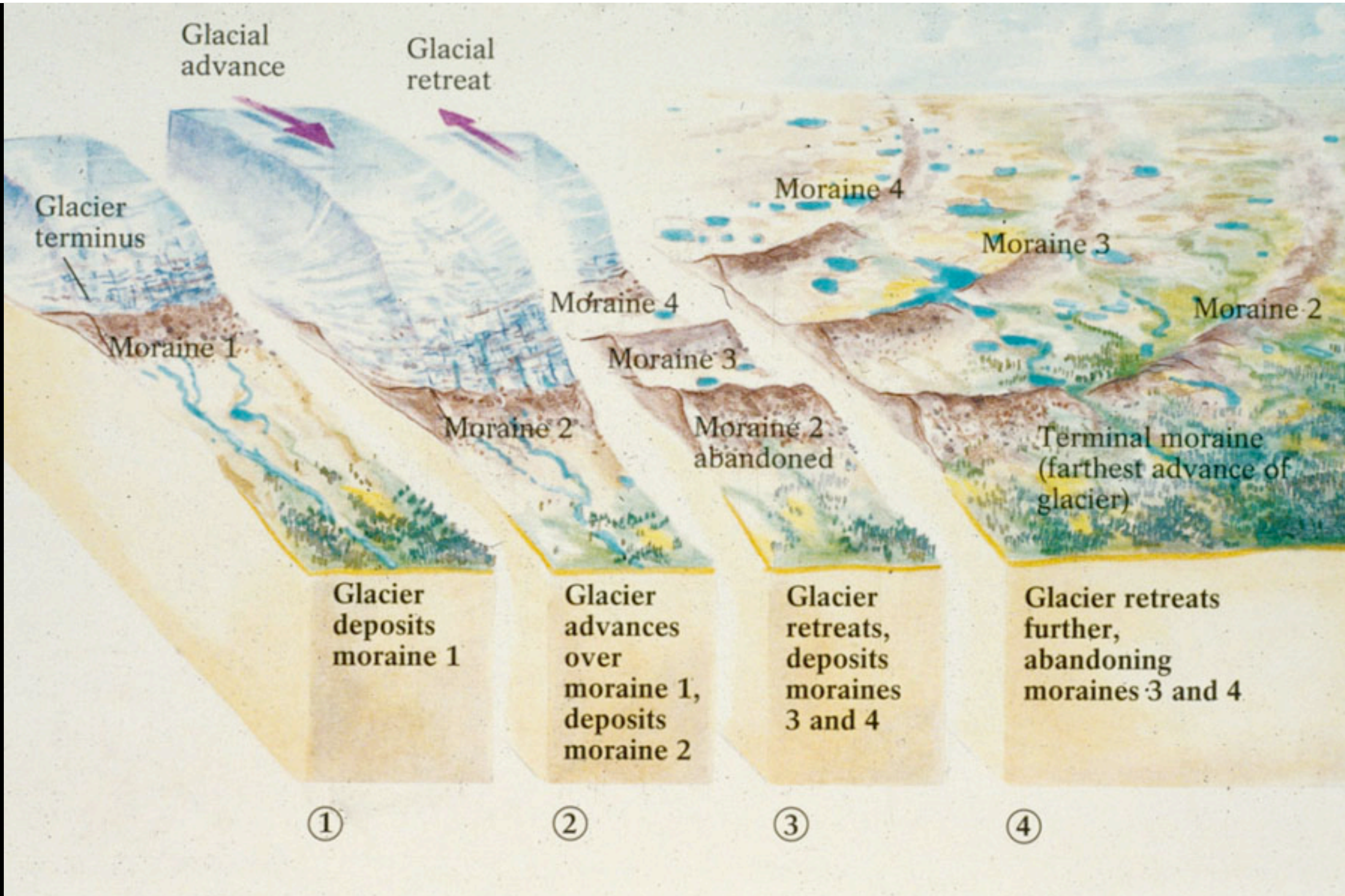
Organics 13,500 ^{14}C years old

Minimum limiting ages provide a constraints on the youngest possible age that a landform or deposit can have. If you have a group of minimum ages, which age will best constrain the age of the underlying deposit?

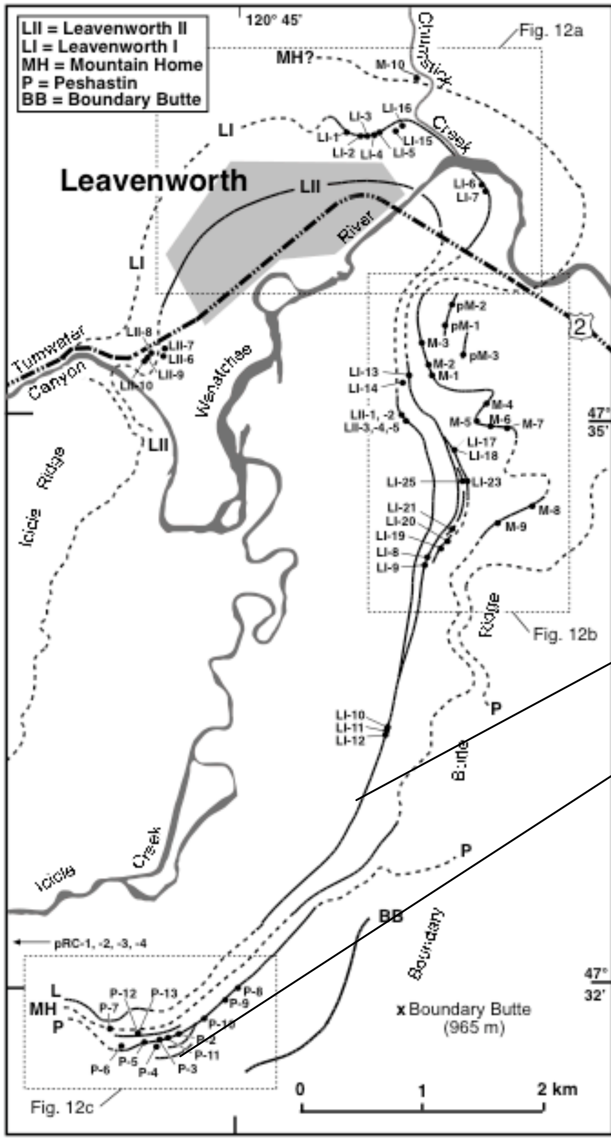




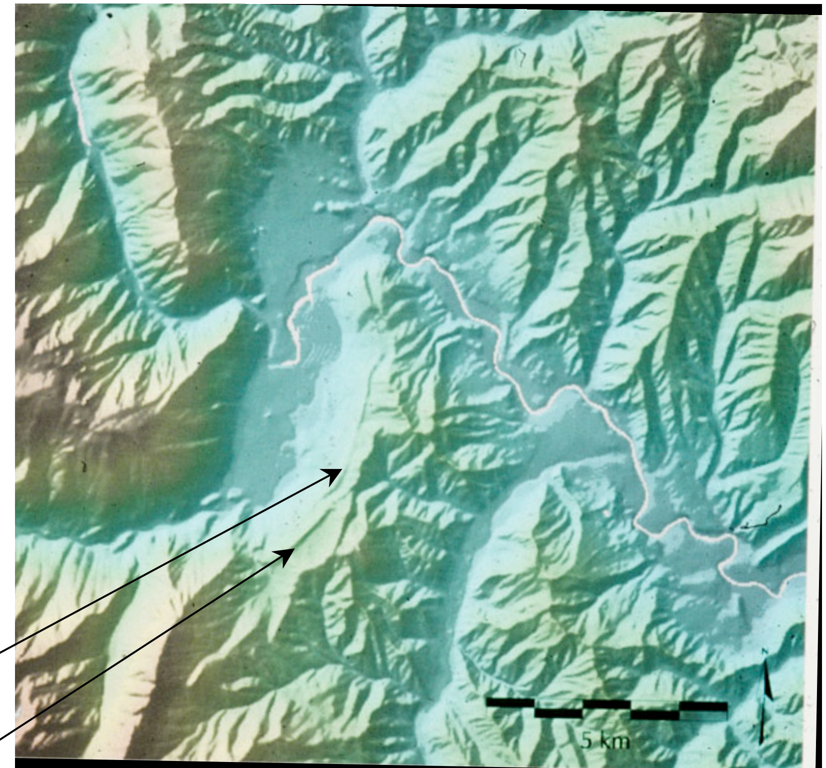
What are the age relationships between Peat 1 (dated at 12,000 ^{14}C years old) and Peat 2 (dated at 22,000 ^{14}C years old) and Tills 1, 2, and 3? What can you say about the numerical ages of the three tills?



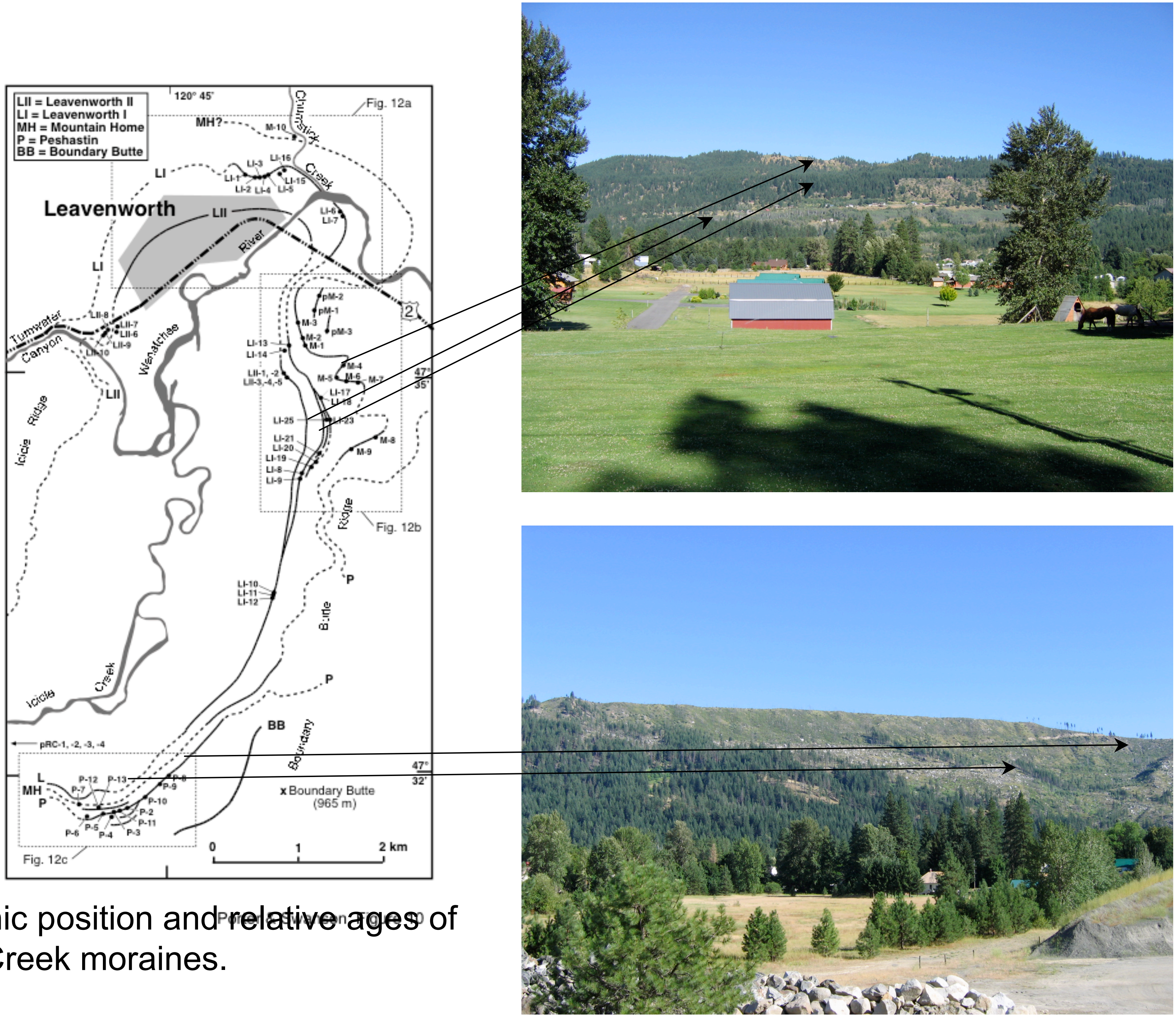
Stratigraphic position and surface morphology of respective moraine sequences provide important information about their relative ages. Which of these factors would provide more useful information regarding the magnitude of age difference between respective moraines?



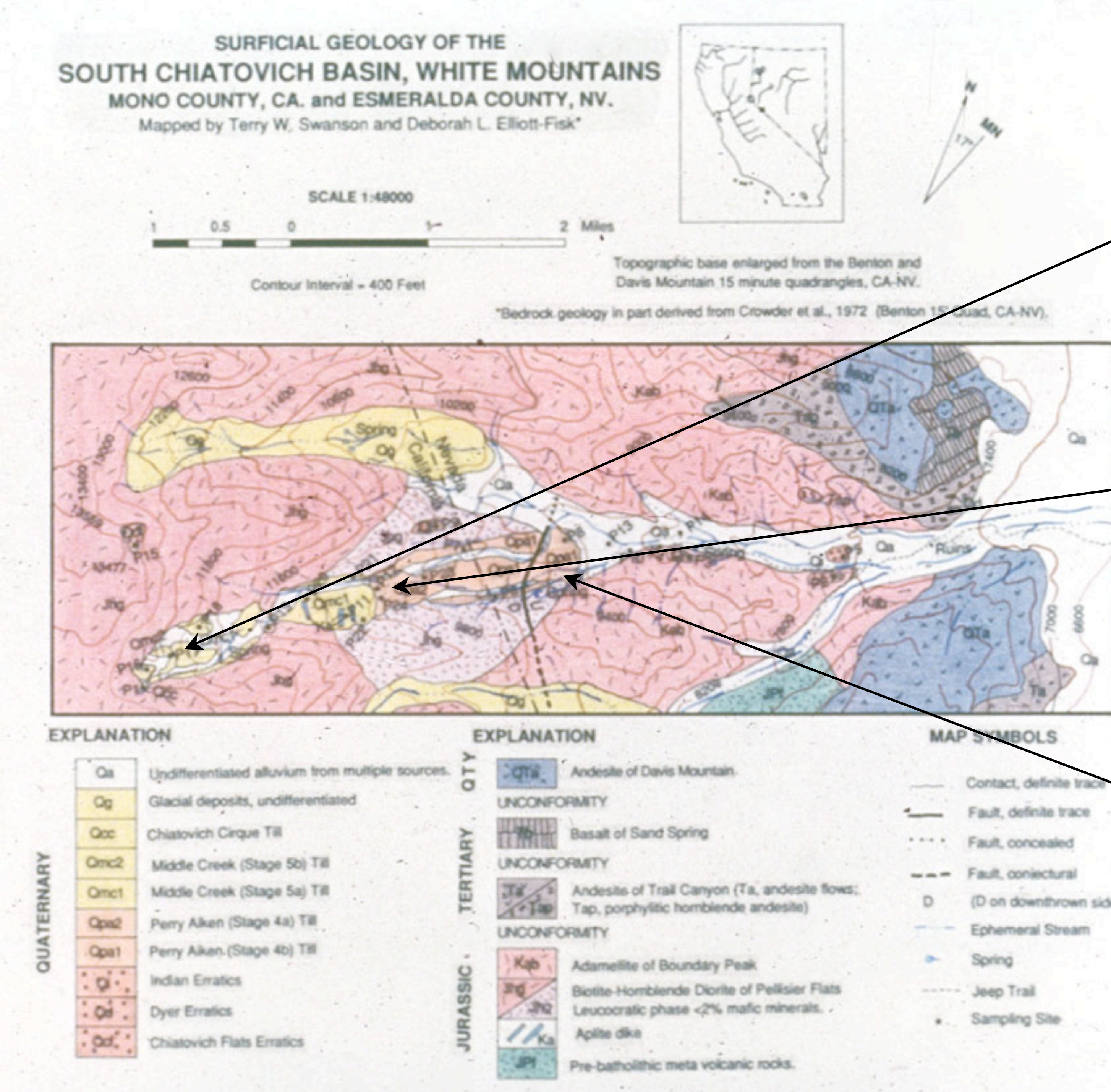
Porter & Swanson, Figure 10



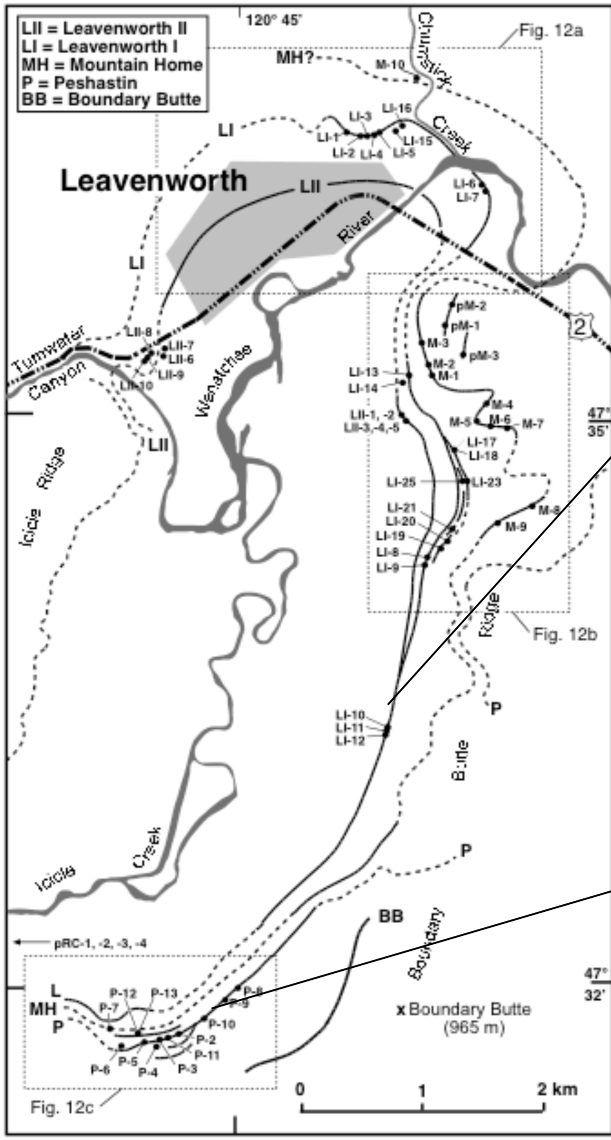
Moraine stratigraphy of the Icicle Creek drainage, WA. DEM and map are oriented in the same direction with north at the top. Outboard moraines are stratigraphically older than inboard moraines.



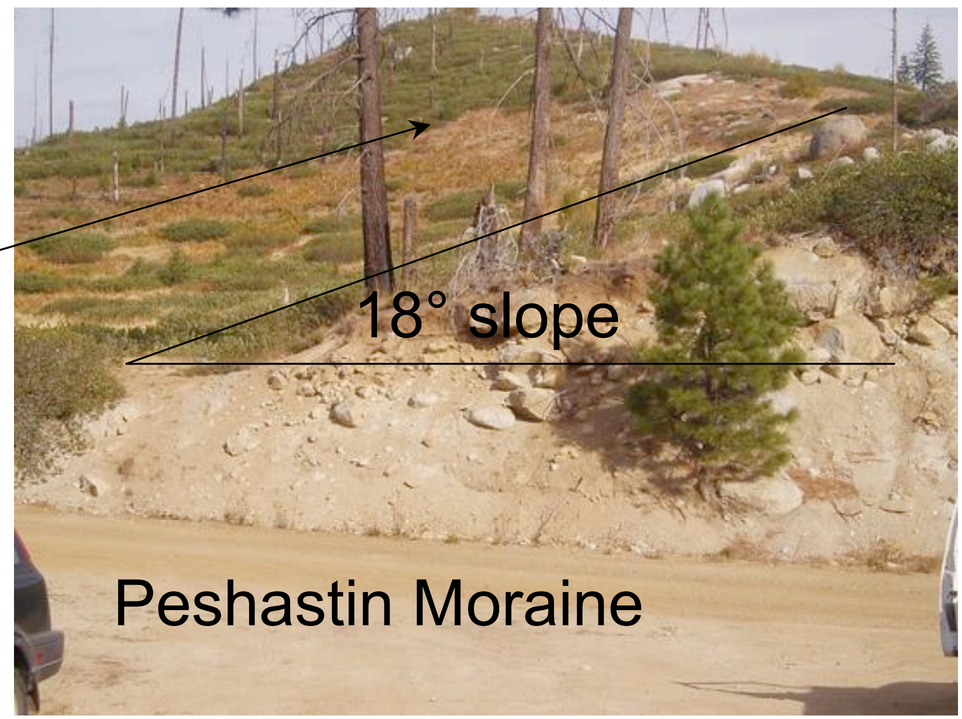
Stratigraphic position and relative ages of the Icicle Creek moraines.


SURFICIAL GEOLOGY OF THE
SOUTH CHIATOVICH BASIN, WHITE MOUNTAINS
MONO COUNTY, CA. and ESMERALDA COUNTY, NV.
Mapped by Terry W. Swanson and Deborah L. Elliott-Fisk*
SCALE 1:48000
1 0.5 0 1 2 Miles
Contour Interval = 400 Feet
Topographic base enlarged from the Benton and Davis Mountain 15 minute quadrangles, CA-NV.
*Bedrock geology in part derived from Crowder et al., 1972 (Benton 15' Quad, CA-NV).
MN
EXPLANATION
QUATERNARY
Qa Undifferentiated alluvium from multiple sources.
Qg Glacial deposits, undifferentiated
Qcc Chiatovich Cirque Till
Qmc2 Middle Creek (Stage 5b) Till
Qmc1 Middle Creek (Stage 5a) Till
Qpa2 Perry Aiken (Stage 4a) Till
Qpa1 Perry Aiken (Stage 4b) Till
Qi Indian Erratics
Qd Dyer Erratics
Qcf Chiatovich Flats Erratics
EXPLANATION
QTY
QTa Andesite of Davis Mountain
UNCONFORMITY
TERTIARY
Tb Basalt of Sand Spring
UNCONFORMITY
Ta Tap Andesite of Trail Canyon (Ta, andesite flows; Tap, porphyritic hornblende andesite)
UNCONFORMITY
JURASSIC
Kab Adamellite of Boundary Peak
Jhg Jhg2 Biotite-Hornblende Diorite of Pellisier Flats Leucocratic phase <2% mafic minerals.
Ka Aplite dike
JPl Pre-batholithic meta volcanic rocks.
MAP SYMBOLS
Contact, definite trace
Fault, definite trace
Fault, concealed
Fault, conjectural
D (D on downthrown side)
Ephemeral Stream
Spring
Jeep Trail
Sampling Site

Cross-cutting relations between the Mono Basin (moraine crests shown as white dashed lines) and Tahoe (moraine crest shown as yellow dashed line) moraines in the Bloody Canyon drainage in the Sierra Nevada.



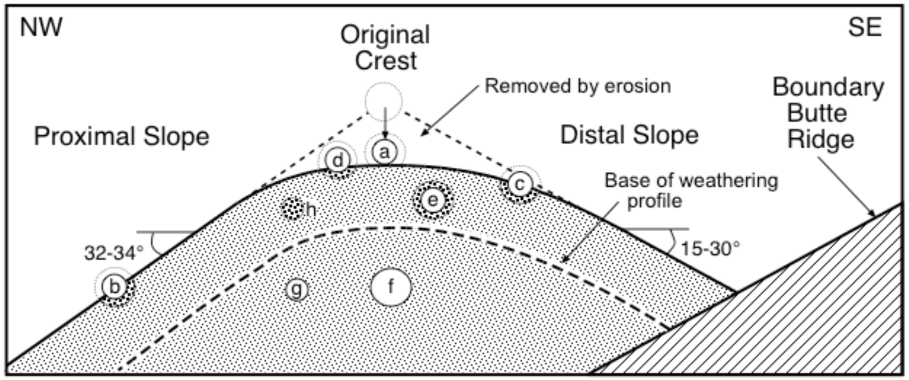
Porter & Swanson, Figure 10



Moraine Diffusion

Moraines degrade over time by diffusion processes. Moraine slope angles will decrease as the crest is lowered and material accumulates at the toe of the slope. The smaller the moraine, the faster its slope angle will decrease.

The Peshastin-aged moraines are significantly more subdued compared to the younger Leavenworth-aged moraines.

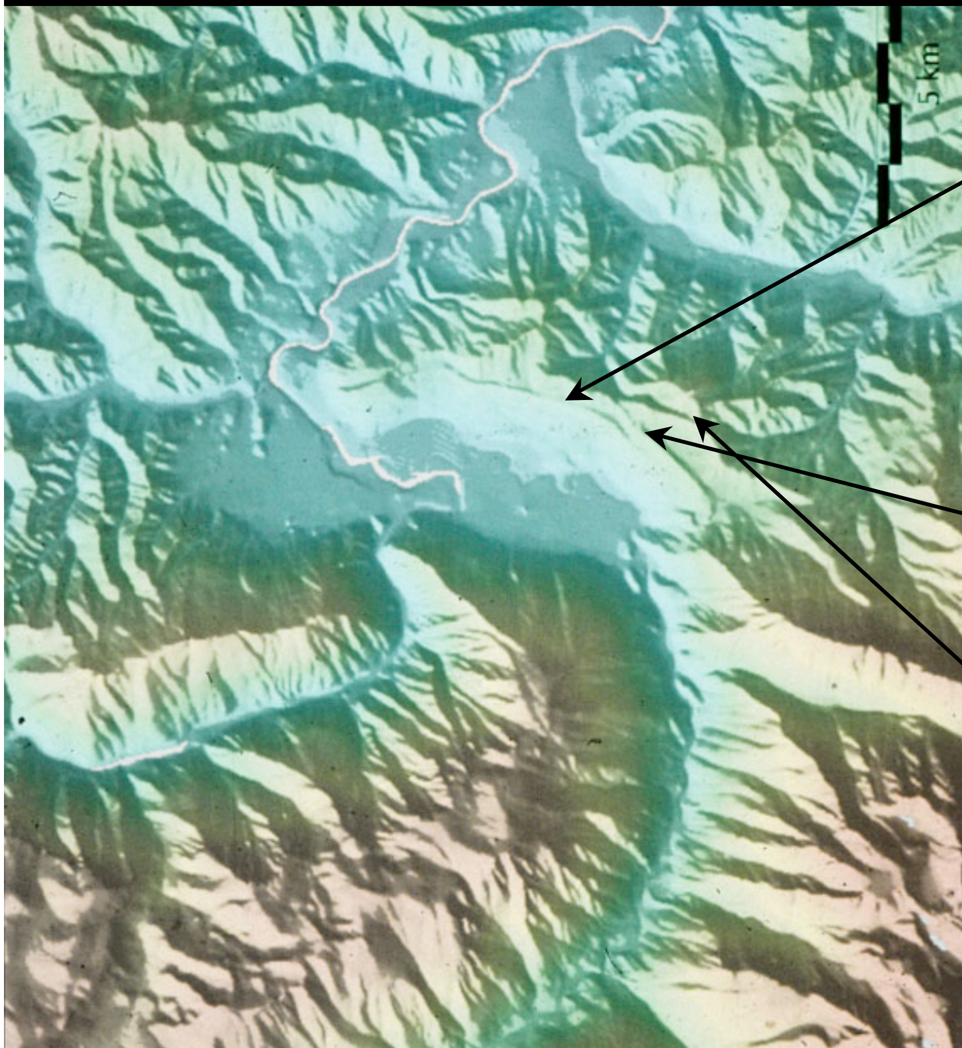


Based on morphology of the above Sierra Nevada moraine sequence and their respective stratigraphic position, how would you map these units. Would you infer that they were deposited over multiple glaciations or deposited as recessional moraines within at single glaciation?

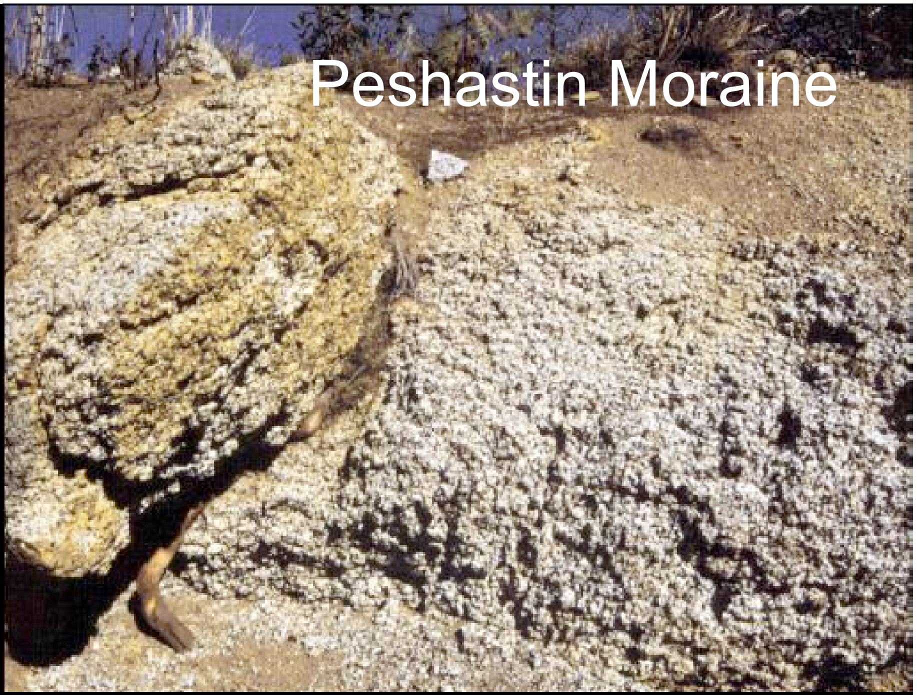
All of the moraines shown in the center of the image have been mapped as being deposited during the Tahoe Glaciation (65,000-75,000years ago) in the Sierra Nevada. Does the morphology of the moraines support this interpretation?

Based on morphology of the above Sierra Nevada moraine sequence (moraine crests shown by dashed white lines) and their relative stratigraphic position, how would you map these units. Were they deposited over multiple glaciations or deposited as recessional moraines within at single glaciation?

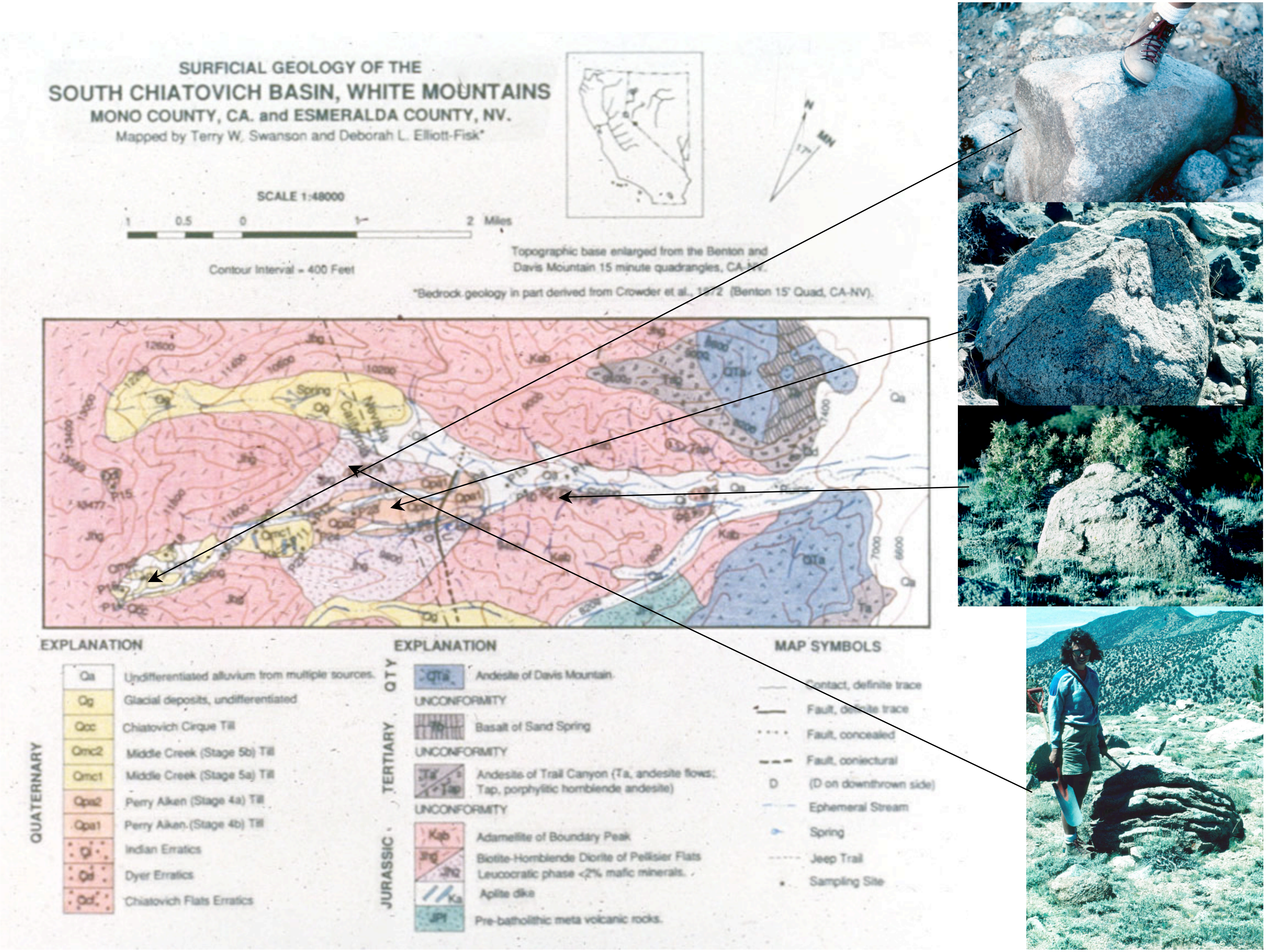
Boulder Frequency vs Moraine Age



Stratigraphic position of moraine sequence in the Icicle Creek drainage, WA and boulder frequency count (from youngest to oldest moraines (top to bottom images).



Surface weathering characteristics on Leavenworth (~22,000 years old) versus Peshastin (~112,000 years old) moraines. Note that the boulders on the older Peshatin moraines have been subjected to greater weathering, and that the mafic minerals have been removed by oxidation reactions leaving felsic minerals with little matrix support. They felsic minerals form an apron of grus at the base of the boulder and will be incorporated into the developing soil.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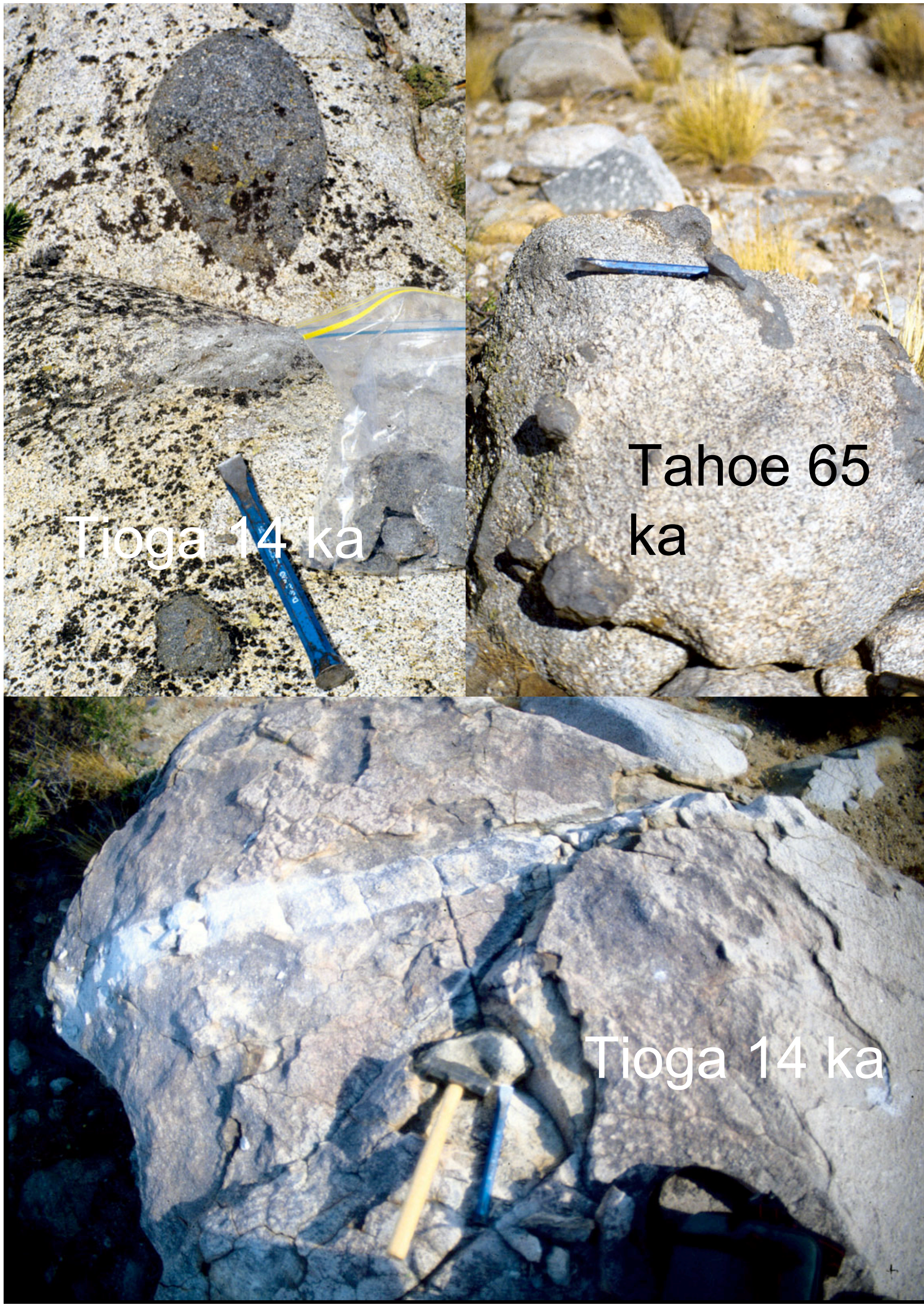


Changes in relief of xenoliths or quartz veins on surface boulders can be used to assign relative ages to moraine boulders or to provide a minimum constraint on surface weathering rates.

The Tahoe-aged boulder found on a moraine along the eastern Sierra Nevada possesses xenoliths with much greater relief relative to the surface of the boulder. The fine-grained xenoliths are more resistanct to chemical weathering processes compared to coarse-grained matrix rock.

Quartz veins similiarly stand in relief as the less resistant matrix rock is chemically weathered.

Rills form from solution weathering of limestone boulder on 14,000 year old moraine. Compare the depth of rilling on the subsequent two slides.

What factors may account for increasing depth of rilling on the limestone boulders.

If environmental factors are held constant what factor will explain greater weathering?

Weathering (oxidation) rinds form on the exterior of cobble or boulders as minerals become oxidized.

Weathering rinds propagate from exterior to interior of boulders exposed to the weathering environment.

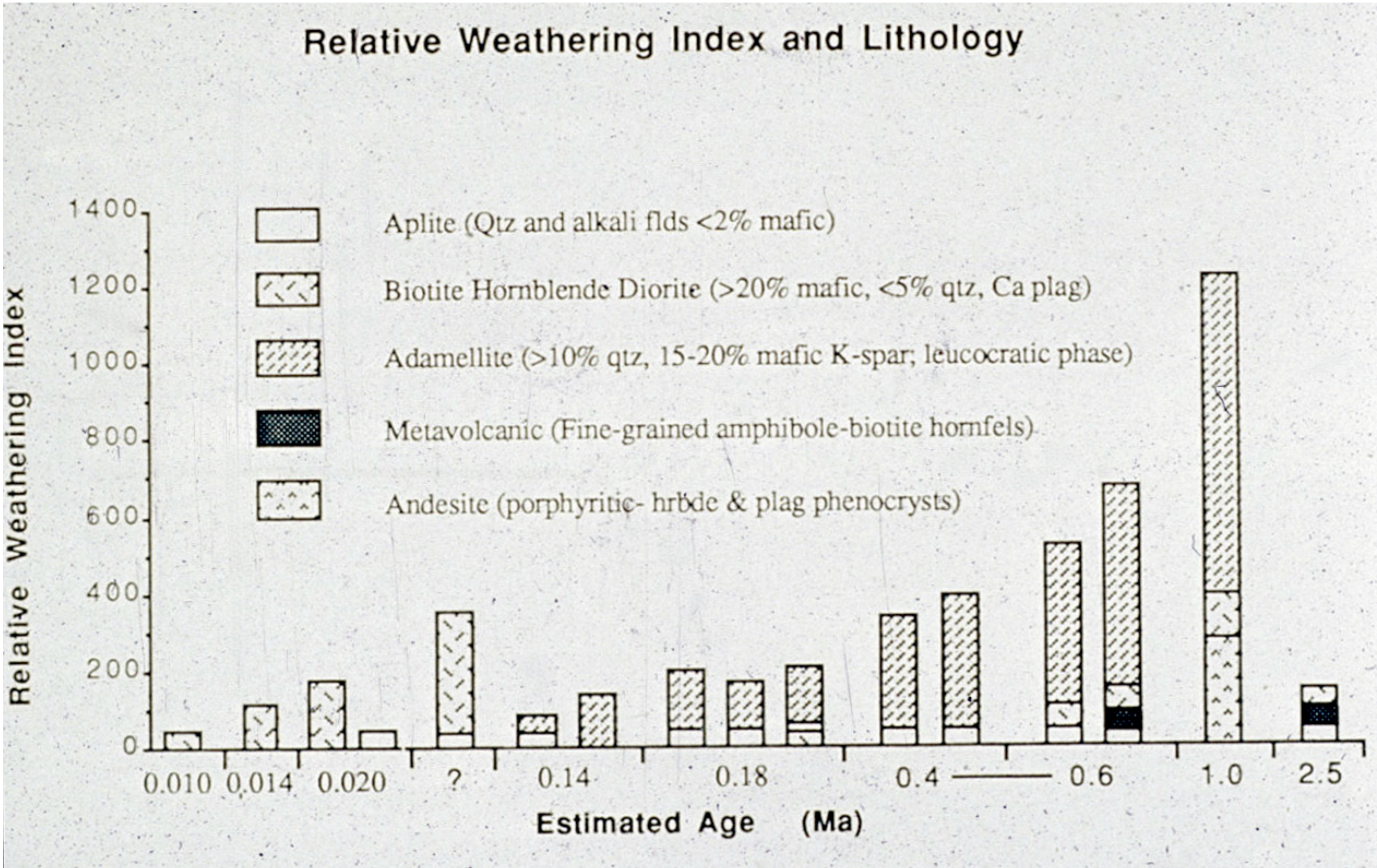
With increasing age the weathering rind width thickens.

Initially, the rate of weathering rind development is a linear relationship to time, but as the surface ages, the rind exterior begins to degrade and be removed. At this point, the growth rate slows, and the time versus rind thickness curve eventually reaches an asymptote.

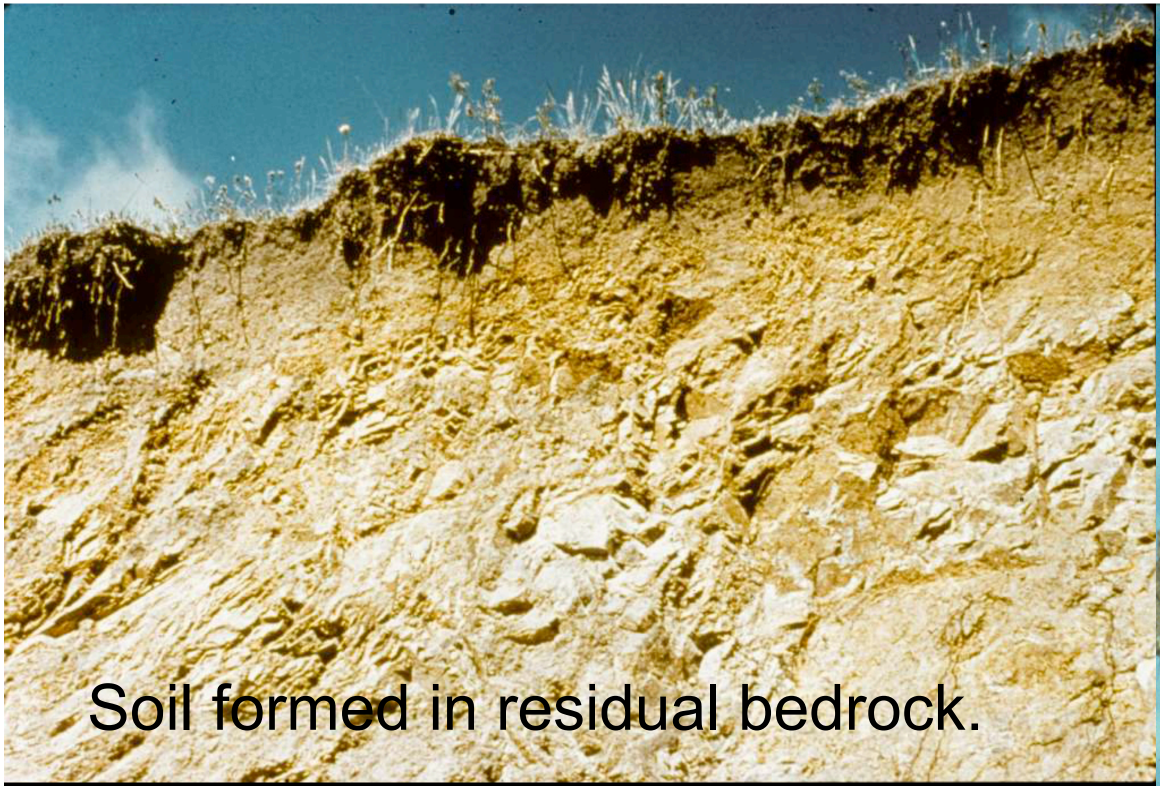
Oxidation rinds have formed around joint blocks that are undergoing spheroidal weathering. The interior core rock is relatively unaltered and the oxidation zone is breaking down the rock leaving unconsolidated grus at the surface.

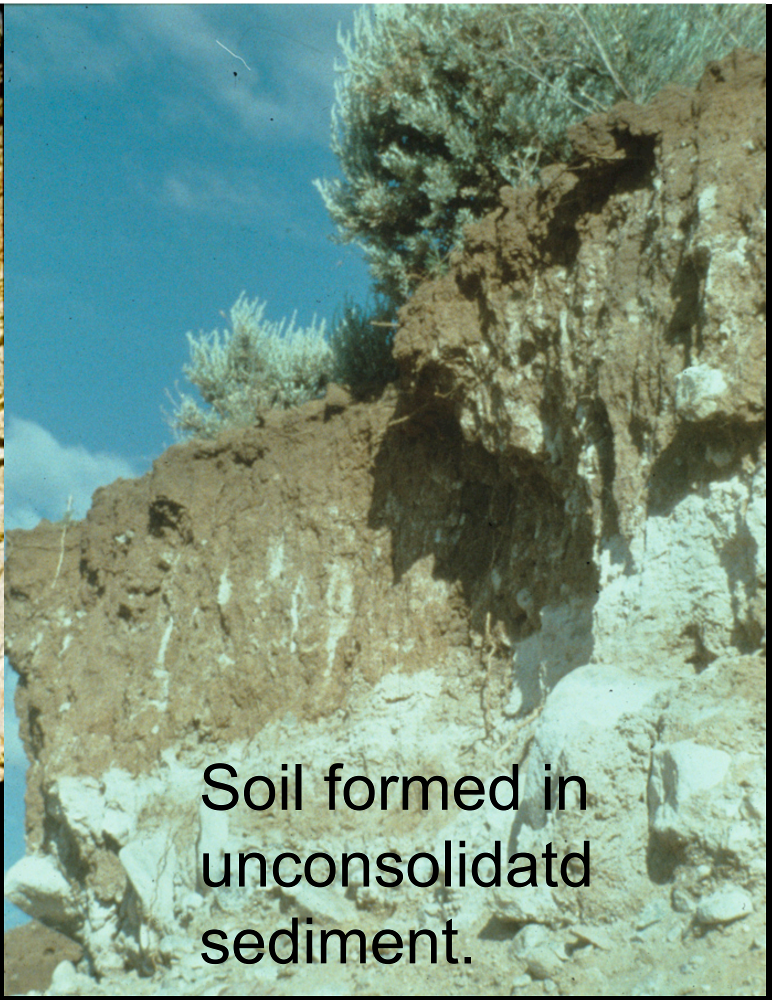
Weathering rinds are very distinct on fine-grained basalt clasts collected from outwash terraces graded to three different aged moraines within the Yakima Drainage along eastern Cascades, WA.

Porter (1976) differentiated three major glacial events based on weathering rind data. I have provided the Leavenworth drainage equivalent glacial events (shownd in red) below the Yakima nomenclature.



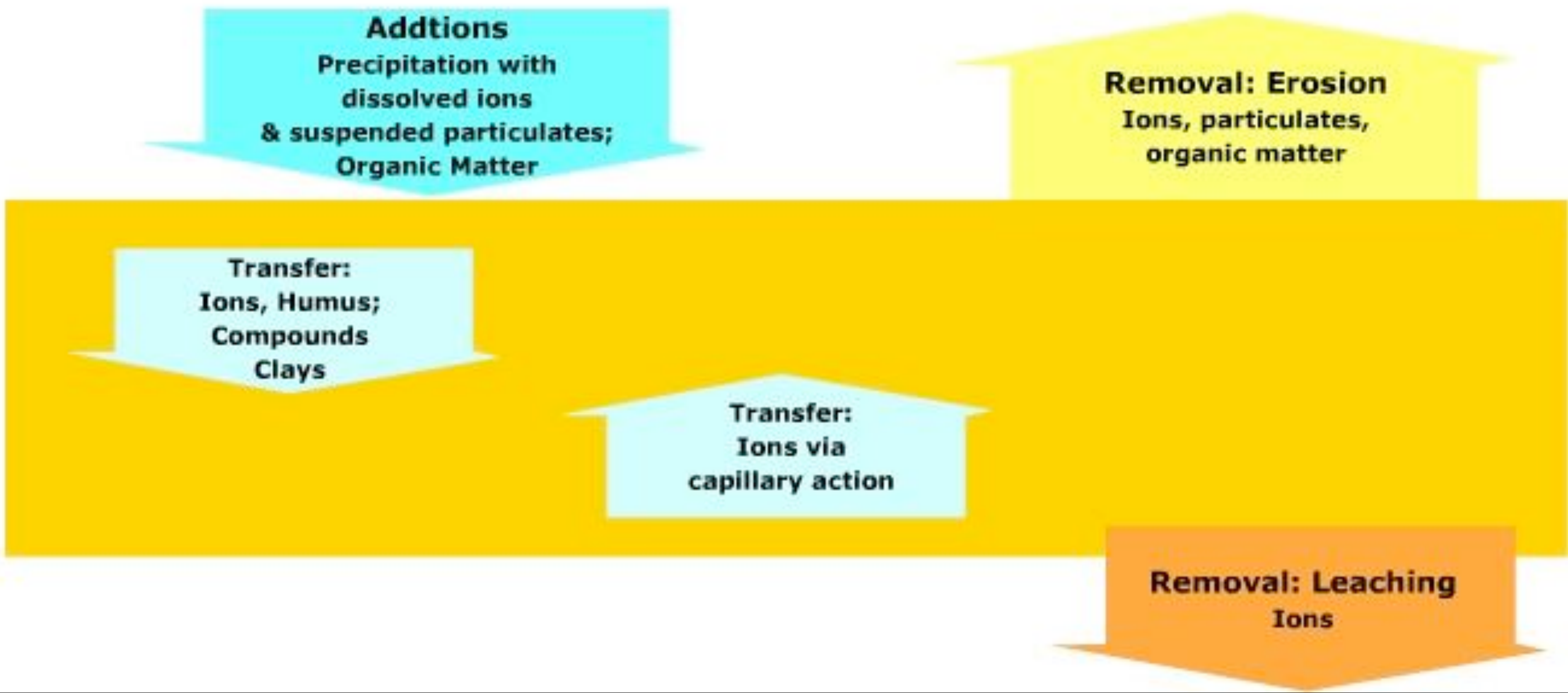
Relative weathering properties versus age Chiatovich Creek drainage, White Mountains, CA.



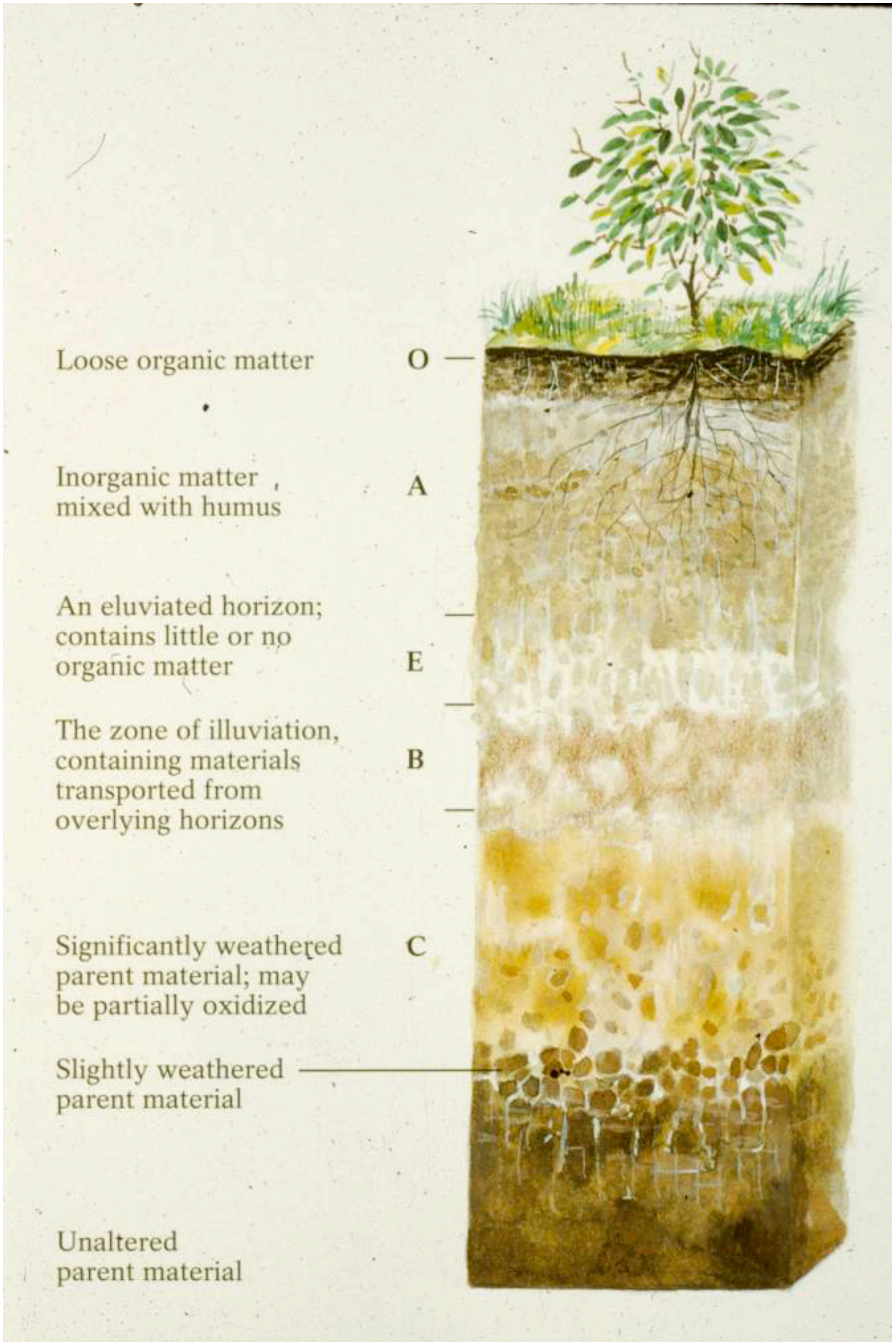


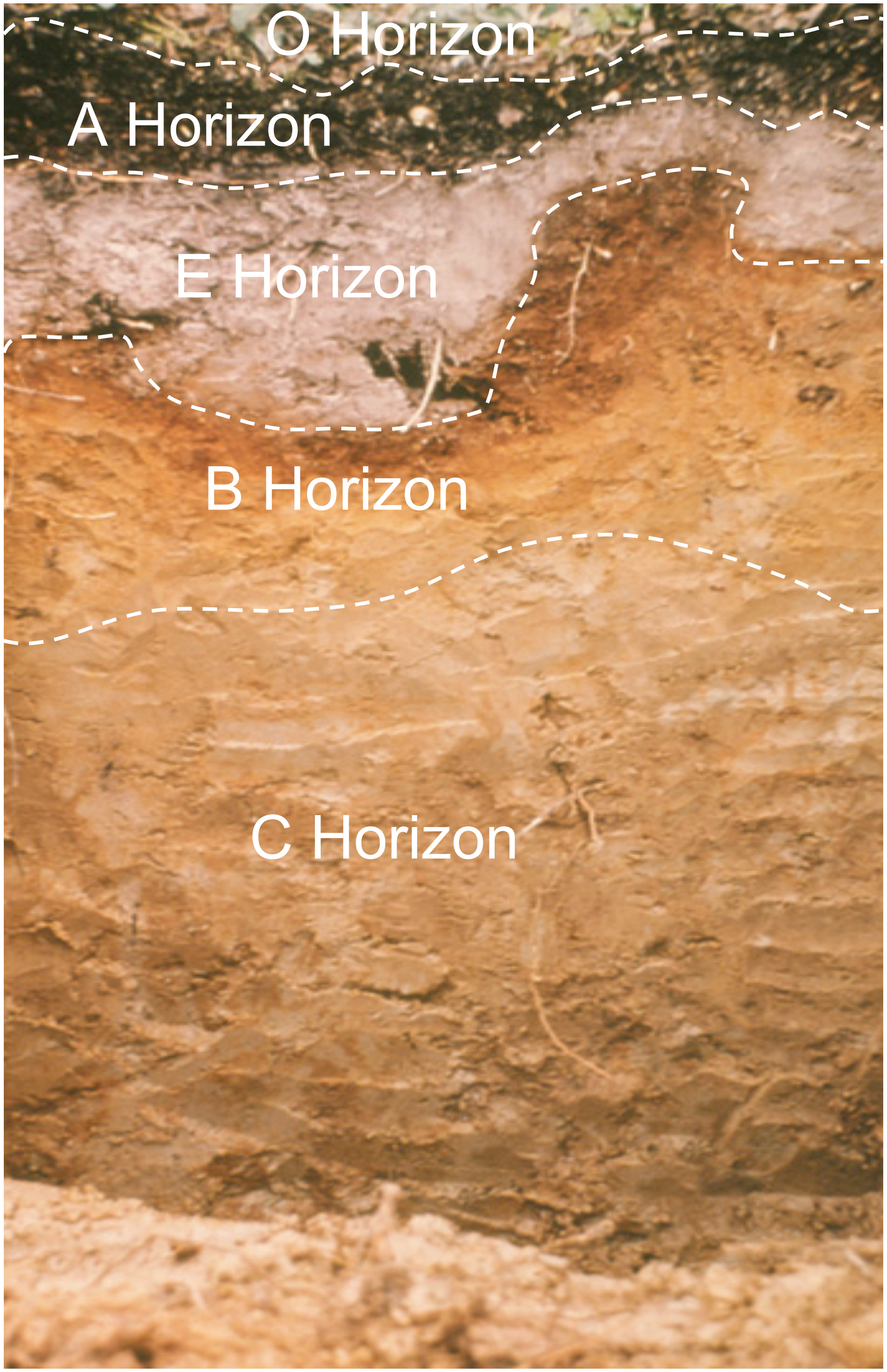
Soils can form in residual bedrock and in unconsolidated sediment. Soils are formed by the same processes that weather rock and the rate of soil development is influenced by the same environmental factors that control weathering rate. Soils can be described as a weathering veneer covering the land surface of the earth.

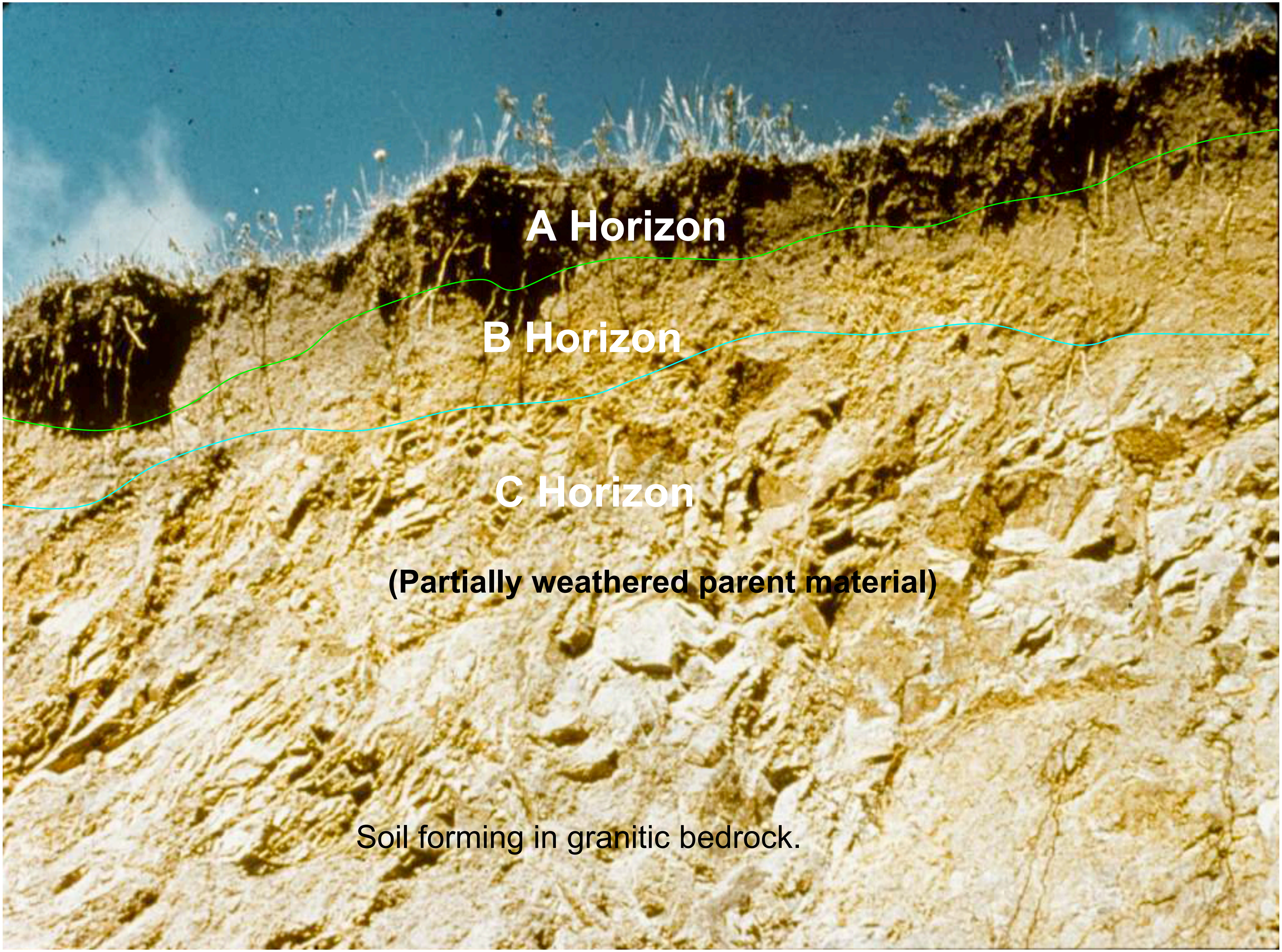
Soil-Forming (Pedologic) Processes

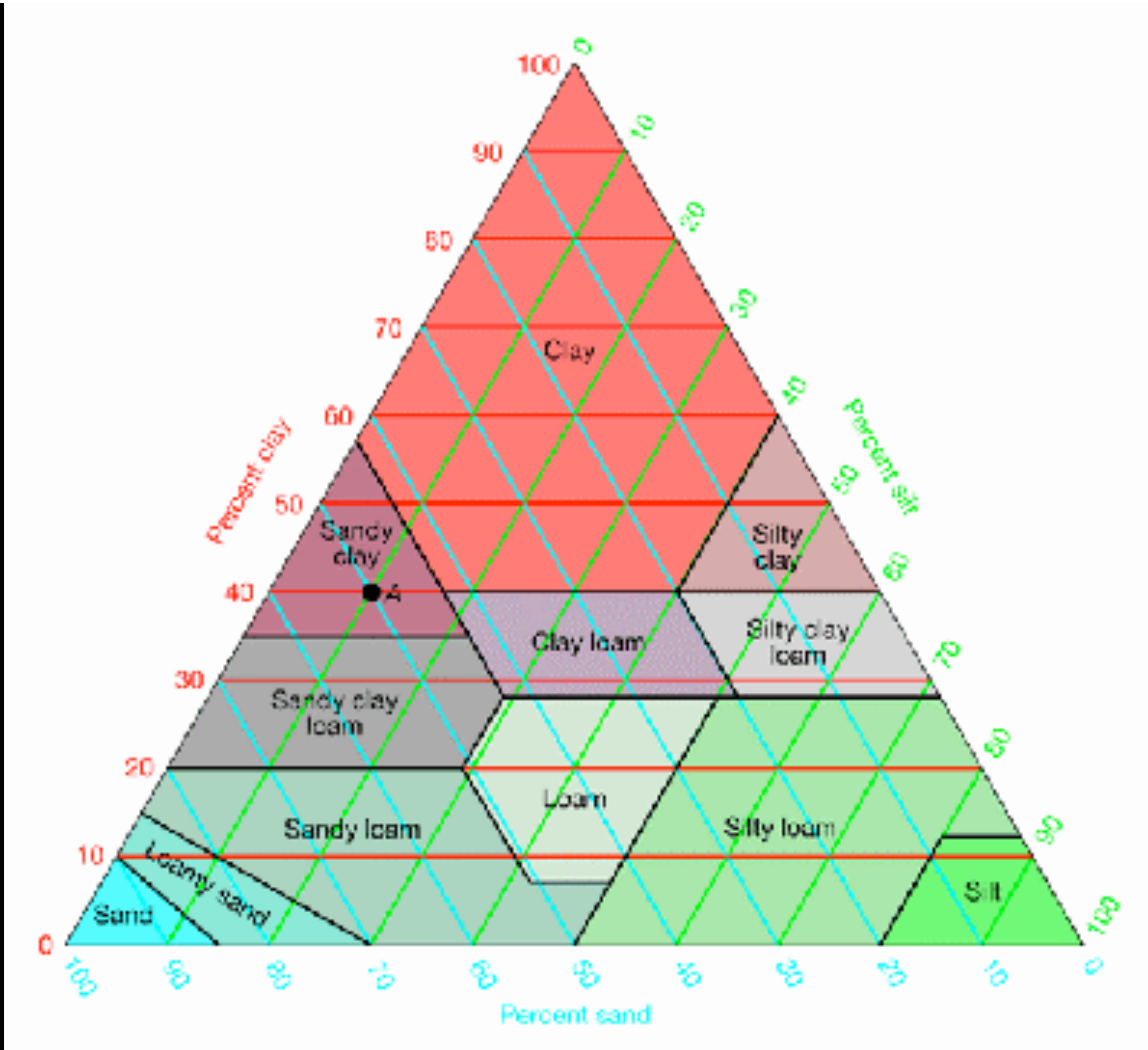


Pedologic processes must be present in order for geologic material to be described as soil.

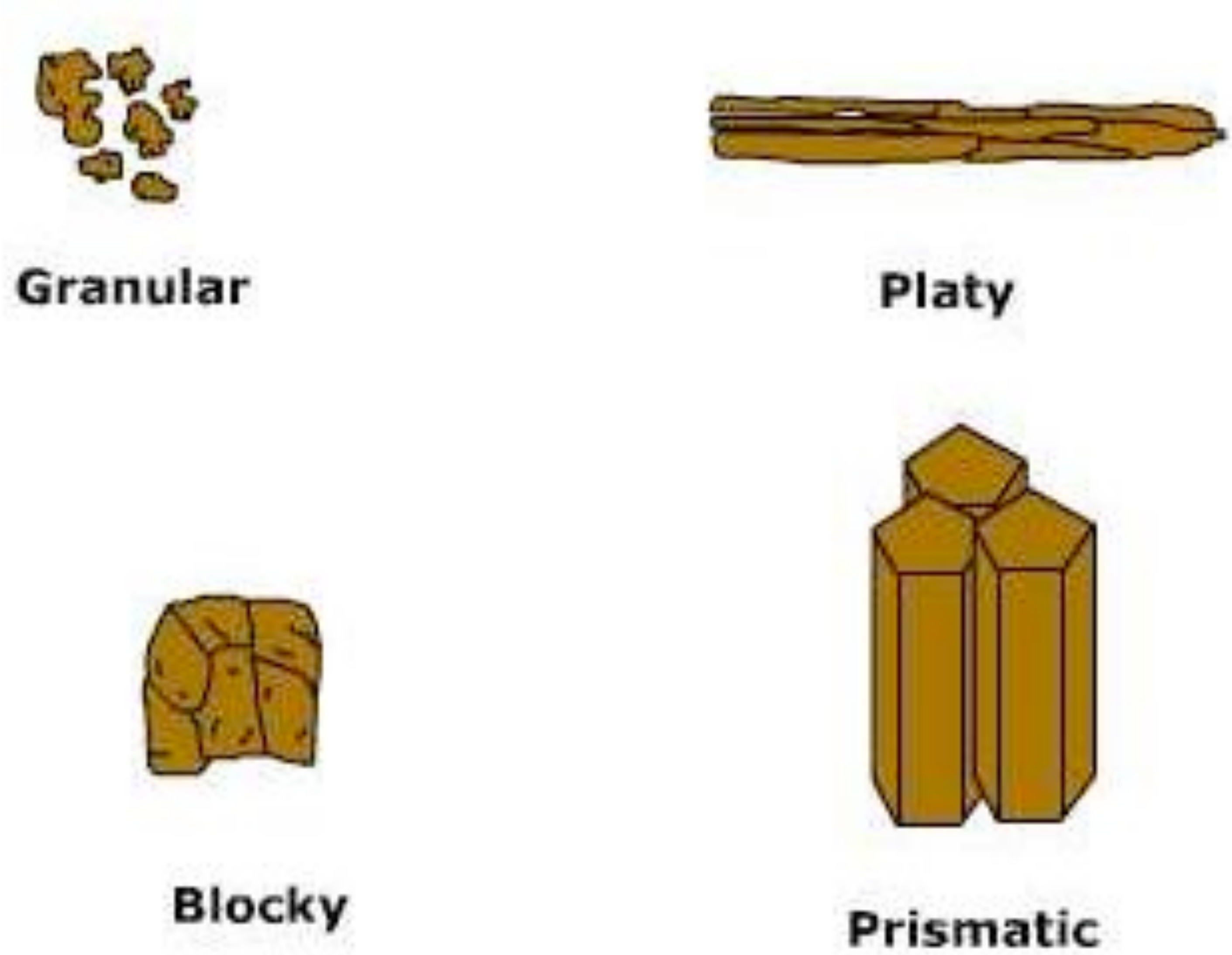

Loose organic matter
O
Inorganic matter mixed with humus
A
An eluviated horizon; contains little or no organic matter
E
The zone of illuviation, containing materials transported from overlying horizons
B
Significantly weathered parent material; may be partially oxidized
C
Slightly weathered parent material
Unaltered parent material


O Horizon
A Horizon
E Horizon
B Horizon
C Horizon


A Horizon
B Horizon
C Horizon
(Partially weathered parent material)
Soil forming in granitic bedrock.



The fine (< 2 mm) textural component of a soil horizon is subdivided into sand, silt and clay. Soil textures are based on the respective % of each fraction.



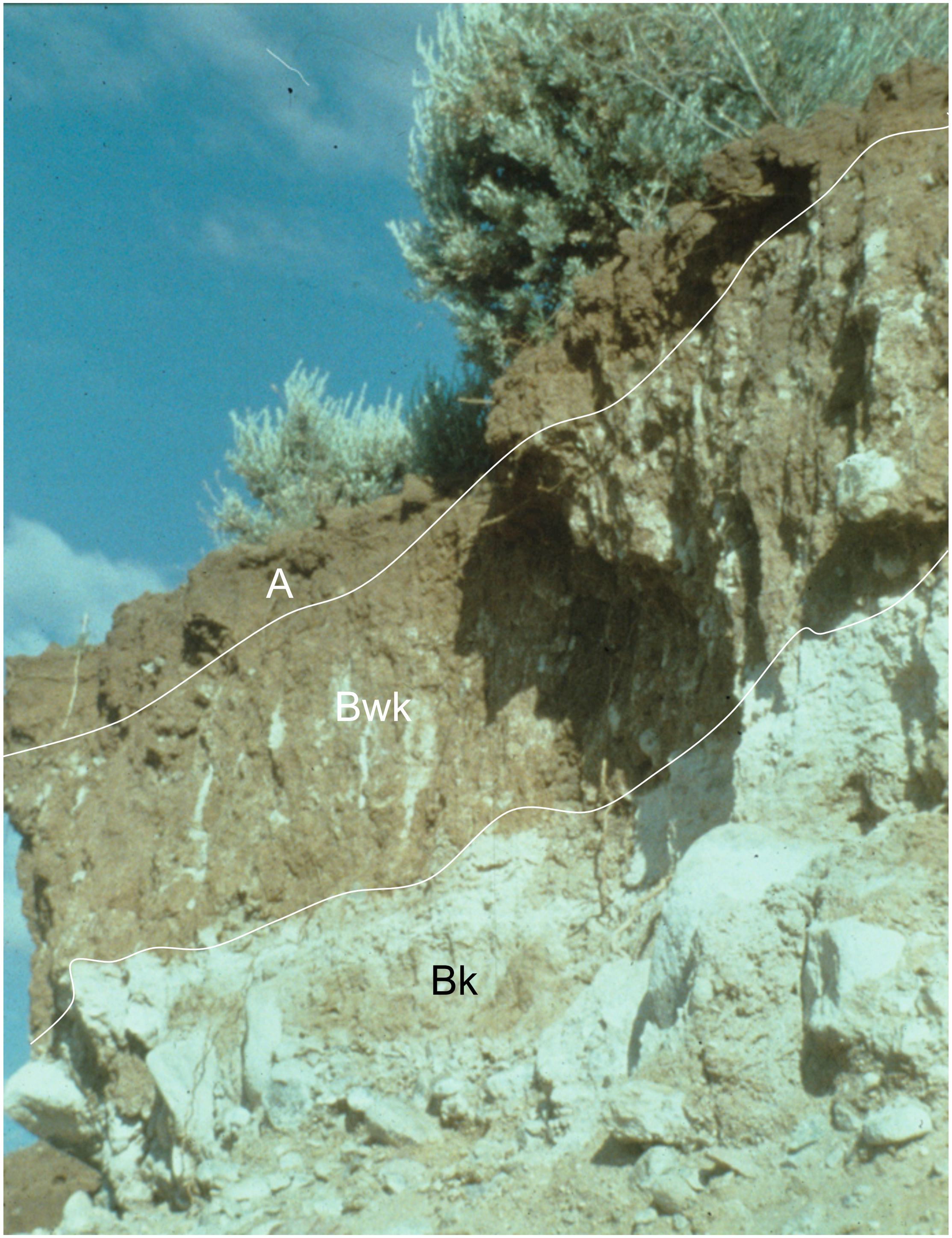
Soil structure tends to trend towards more blocky structures as soils develop. Lithology and composition also play a role in soil structure.

Mobility

- Mobility is the ability of elements to be transported out of the weathering zone
- ion mobility

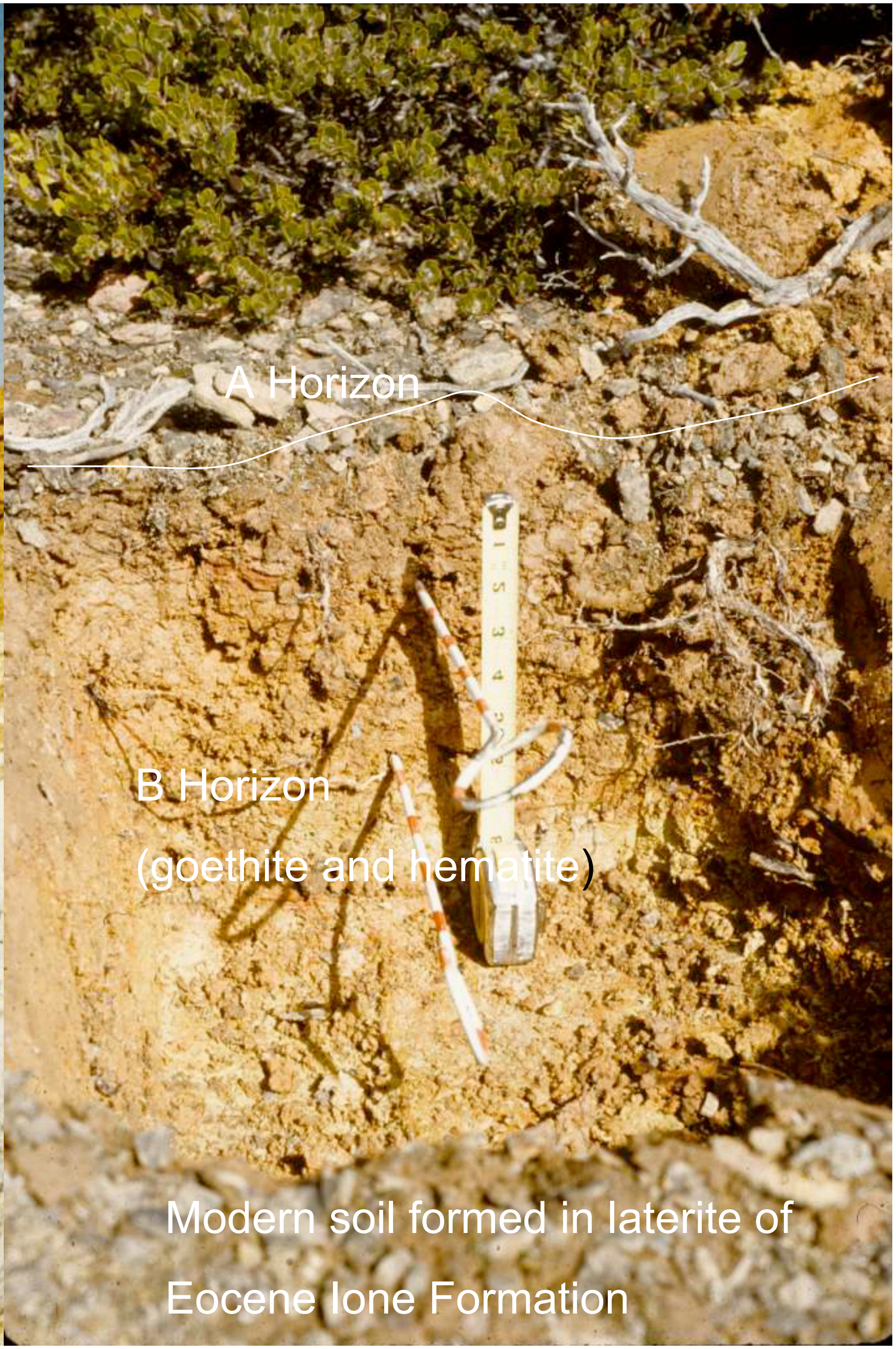
  Ca>Na>Mg>K>Si>Fe>Al

Al considered immobile



Formation of caliche soils in arid climates.


Eocene oxisol, Ione, CA


A Horizon
B Horizon
(goethite and hematite)
Modern soil formed in laterite of
Eocene Ione Formation

Factors of Soil Development

Climate

Organisms

Relief

Parent material

Time

(Jenny, 1941)

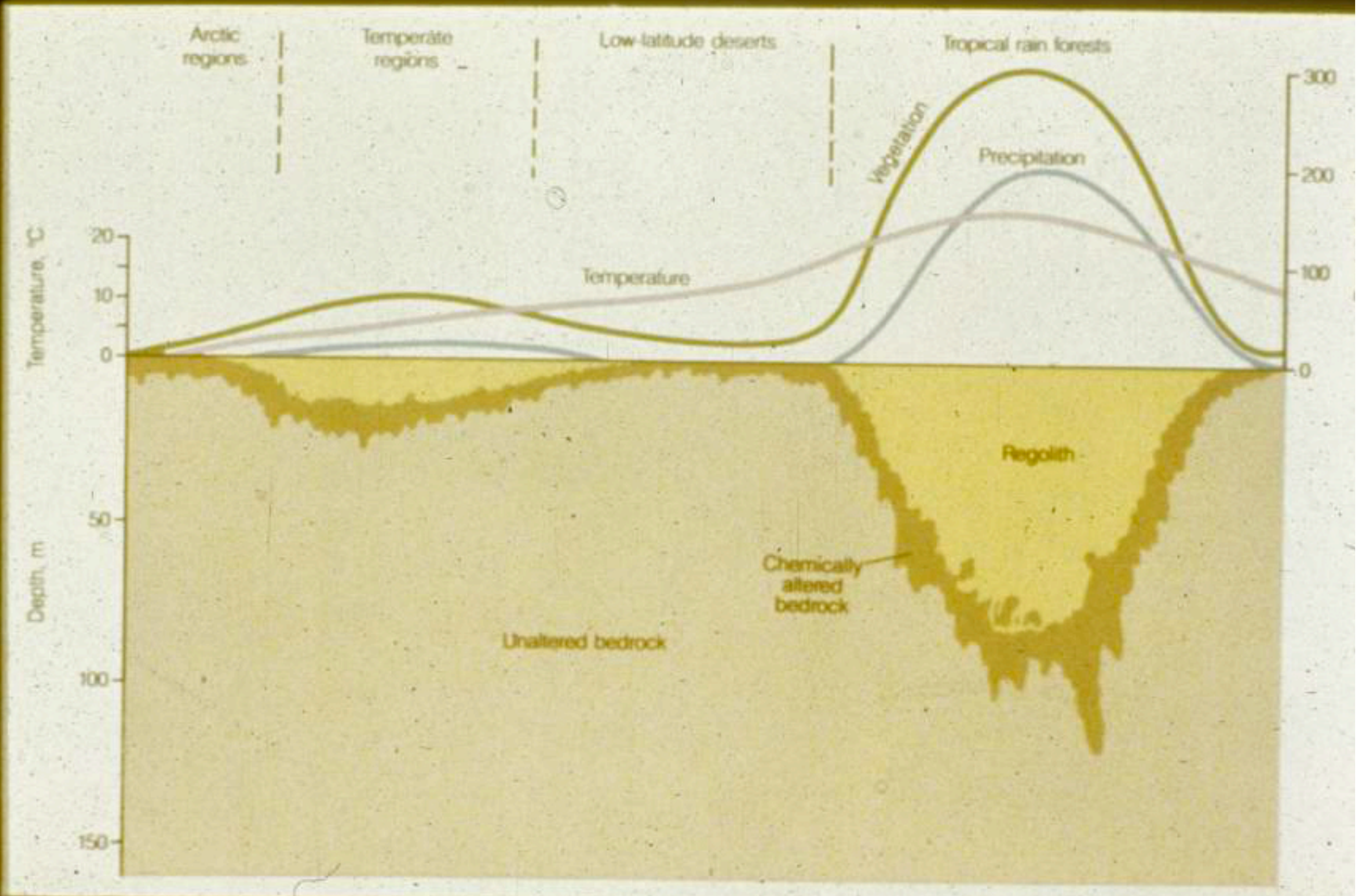
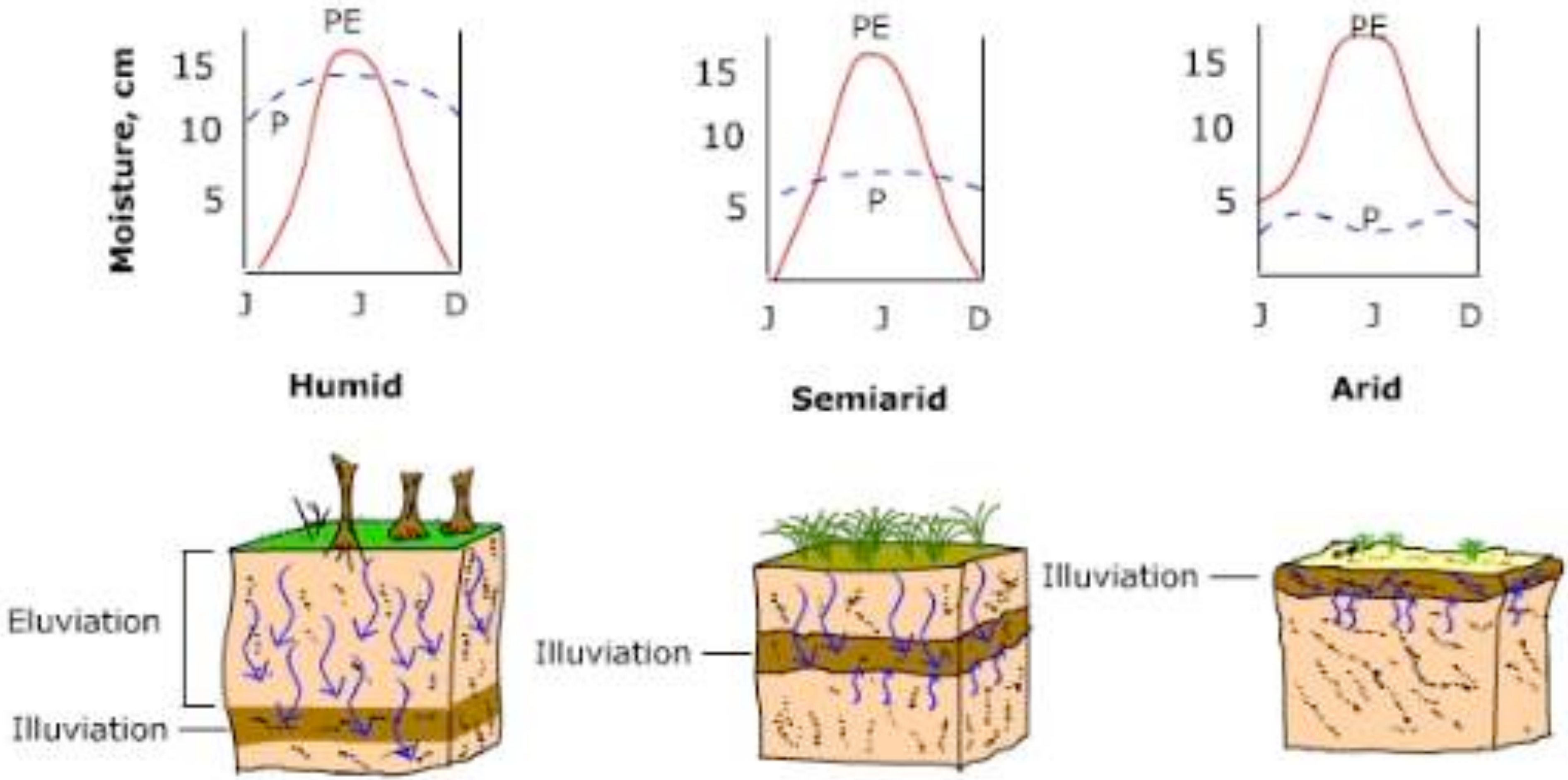
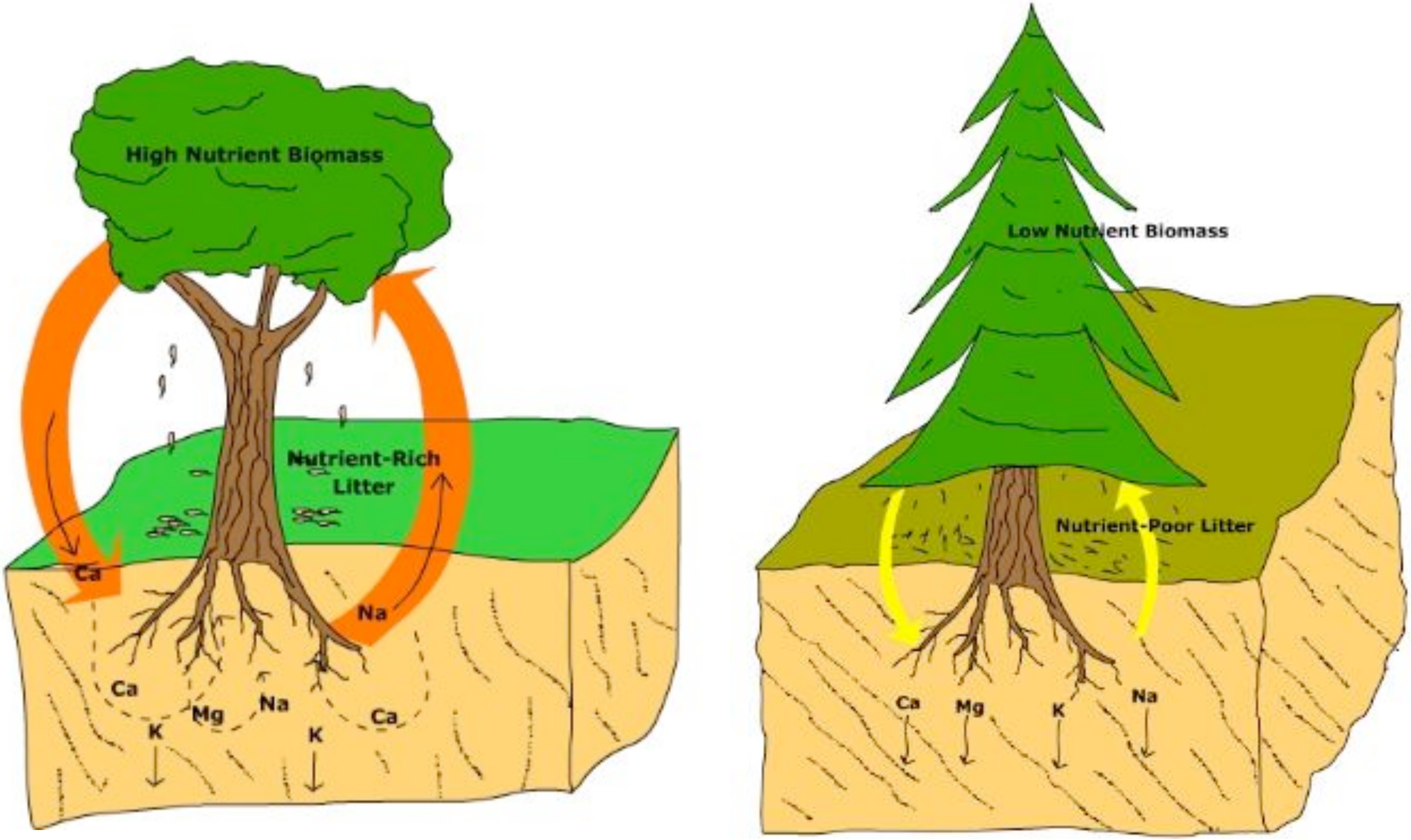


Figure 9.13 Climate and weathering

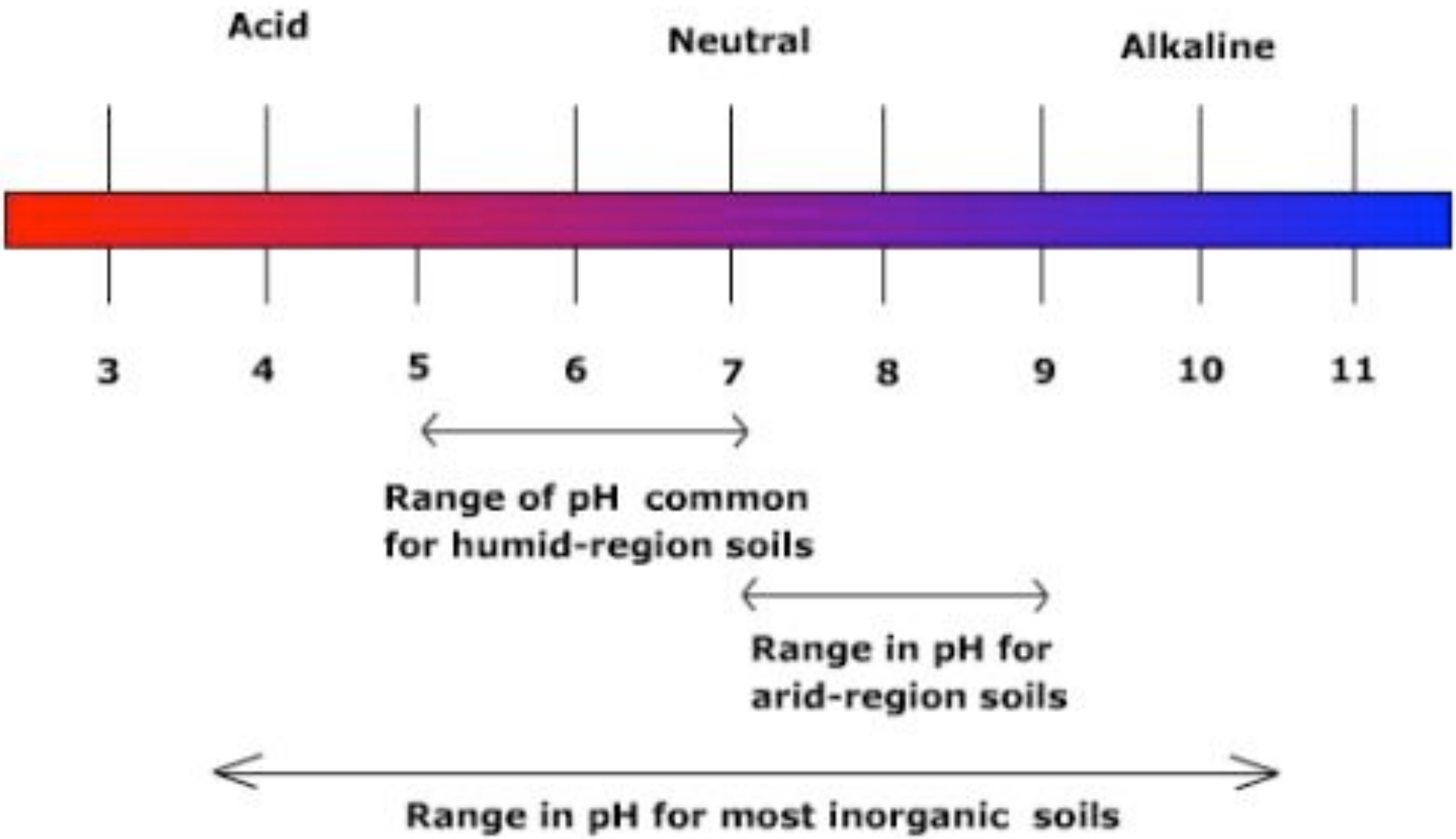
(After N. M. Strakhov, 1967, *Principles of Lithogenesis*, trans. J. P. Fitzsimmons, Edinburgh: Oliver and Boyd, vol. 1)



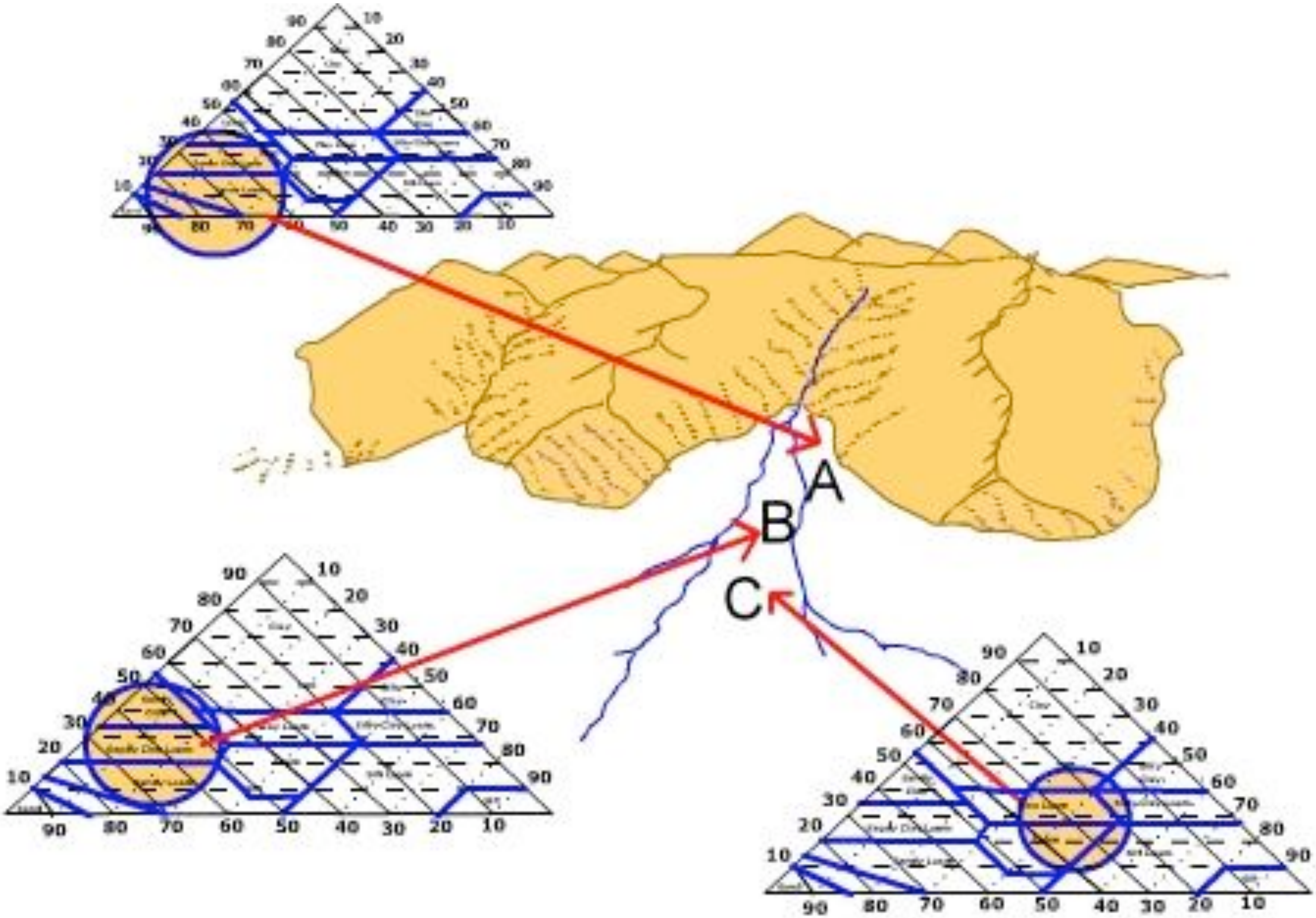
Moisture, cm
15
10
5
PE
P
J
J
D
Humid
Semiarid
Arid
Eluviation
Illuviation
Illuviation
Illuviation

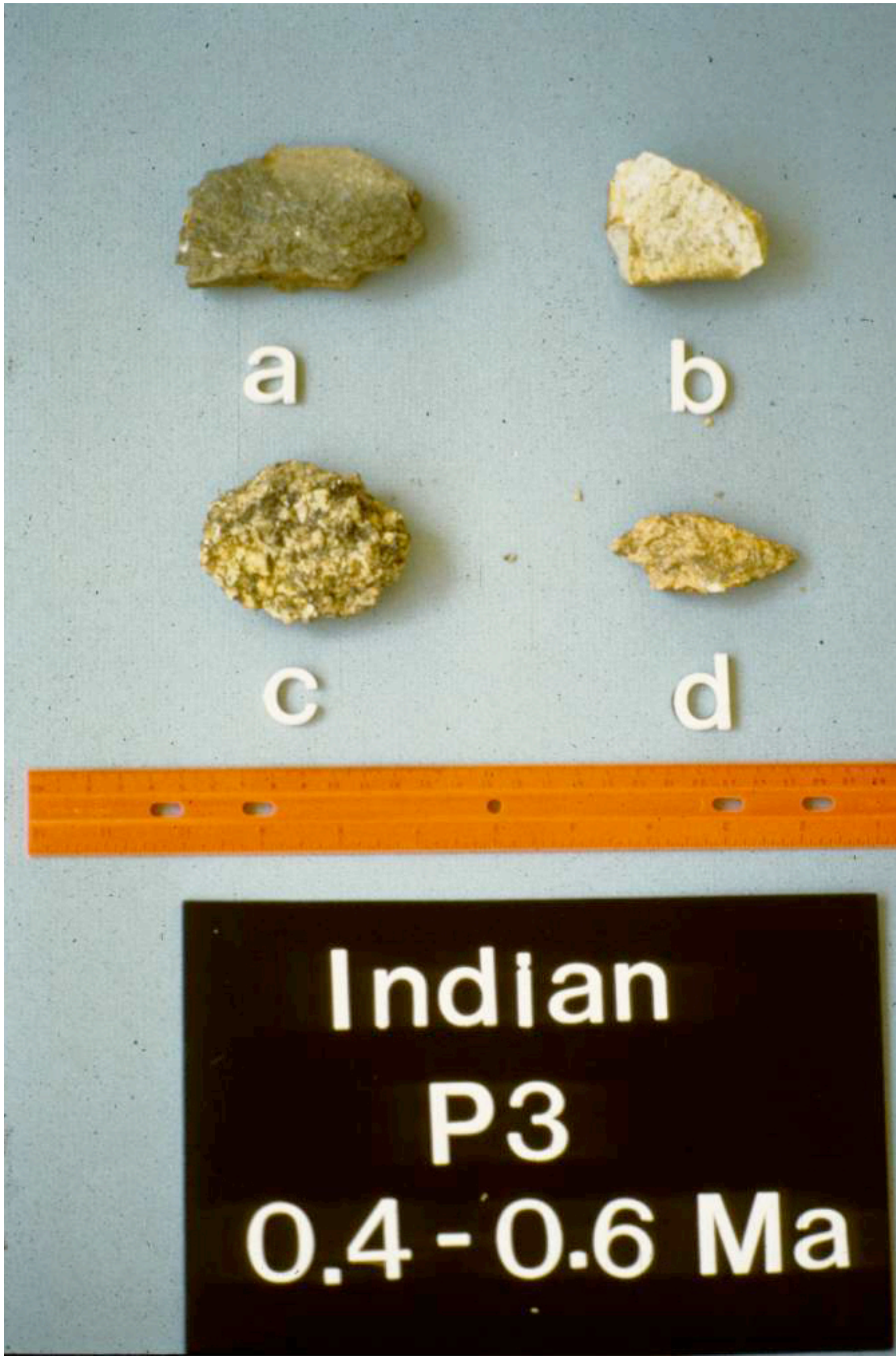


Vegetation affects soil chemistry and available cations. High acidic soils, such as those associated with boreal conifer forests, tend to nutrient-poor as cations are leached from the profile.


Acid
Neutral
Alkaline
3
4
5
6
7
8
9
10
11
Range of pH common
for humid-region soils
Range in pH for
arid-region soils
Range in pH for most inorganic soils

Soil development versus position on a moraine slope. Compare solum depth at crest versus the flank of the Tahoe-aged (~65,000 year old) moraine. The depth of the solum is related to the moraine's diffusivity.


A
B
C



The parent material of a soil plays a major role in its development rate. Composition and structure control chemical weathering rates.

Soil development on a 13,000 year old moraine, Snoqualmie Pass, WA.

Soil development on 75,000 and 150,000 year old moraines.